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On the Cover • Bi-Parental Crossing Rack

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SUGAR CANE BREEDING IN HAWAII

Part II -- 1921 to 1952[1]

A. J. Mangelsdorf[2]

INTRODUCTION

Hawaii was somewhat tardy in initiating its sugar cane breeding program. In 1887 Soltwedel, working in Java, had succeeded in growing seedlings germinated from tassels of a variety represented in his collections under the name "Hawaiian Cane." In 1889, Harrison and Bovell in Barbados also obtained germinations from field-collected tassels. Although the progress of breeding in these two countries was being followed with interest throughout the sugar cane world, it was not until 1905 that Hawaii embarked in earnest upon a program of its own.

The first lot of five thousand seedlings germinated in 1905 resulted in the famed variety H 109 which proved greatly superior to Lahaina and Yellow Caledonia in the irrigated lands. It might have been expected that this remarkable success would have resulted in a prompt intensification of the breeding effort. However, such was not the case. In 1911, an additional 336 seedlings were grown; in 1913, 3684. Apparently two factors were acting as deterrents on further breeding: first, the lack of regional station testing facilities; and second, the absence of a systematic and coordinated program for preliminary testing of unselected seedlings by the plantations. During the twelve-year period from 1905 to 1917, only sixteen thousand seedlings were grown. In 1917, seedling propagation was resumed with renewed energy and during the next four-year period, ending in 1920, 92,332 new seedlings were transplanted to the field nurseries.

This renewed effort, however, failed to produce the hoped for results. None of the newer seedlings proved equal to H 109 or Yellow Caledonia in their respective zones. As time went on, it became increasingly evident that the breeding program was in need of further strengthening. In particular, the following shortcomings were recognized:

1. The breeding collection was scanty.
2. The crossing procedure was time-consuming.
3. The propagation facilities were inadequate.
4. The facilities for field testing were too localized and the testing procedures were in need of systematizing.

The steps taken to correct these shortcomings are now to be examined.

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[1] Sugar Cane Breeding in Hawaii, Part I—1778–1920 by A. J. Mangelsdorf appeared in the Hawaiian Planters' Record, Vol. 50 : 141–160. 1946.

[2] A. J. Mangelsdorf is Principal Geneticist of the Experiment Station, HSPA.

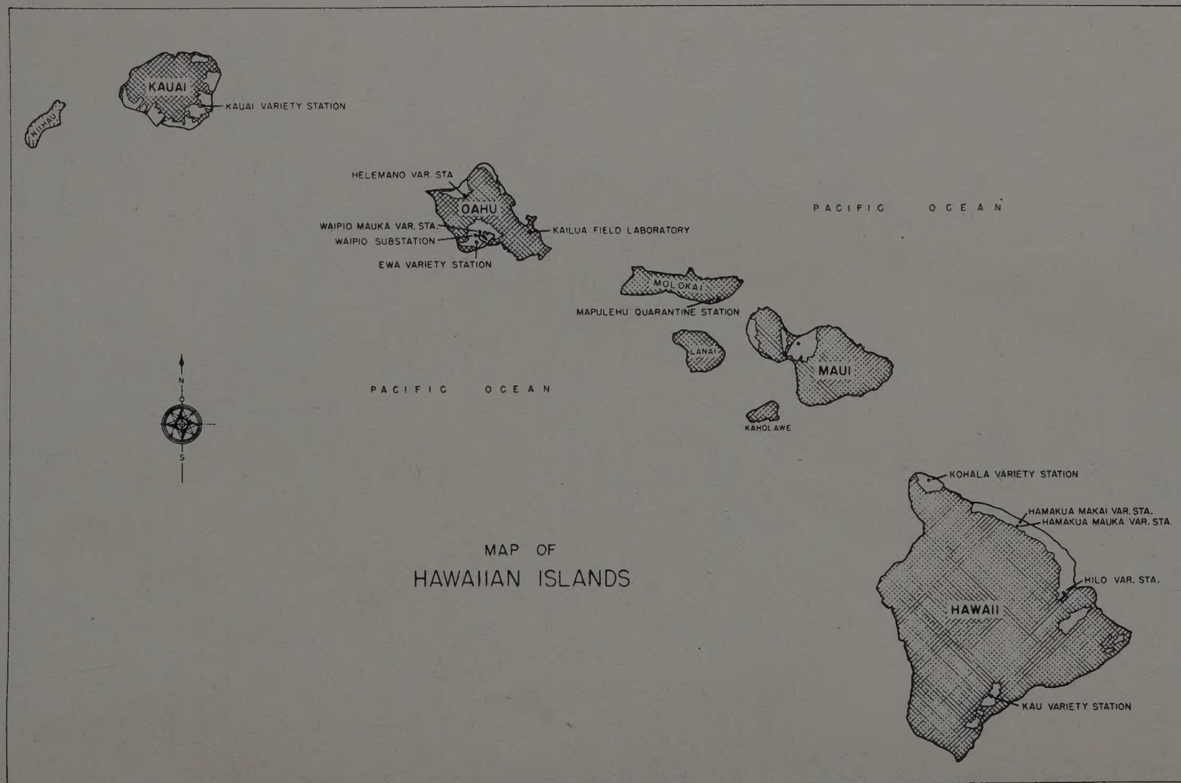

Figure 1. Areas not cross-hatched represent sugar plantations. Locations of the 10 Regional Variety Stations, of the Kailua Field Laboratory, and of the Mapulehu Quarantine Station, are all indicated.

THE BREEDING COLLECTION

Importation of New Breeding Material

The breeding collection at the disposal of the sugar cane breeders in Hawaii in the early 1920's was a meager one. No new varieties had reached Hawaii from other countries since 1905. Only the "noble" species, *Saccharum officinarum*, was fairly well represented. Many crosses between varieties of this species had been explored during the period 1905–1920; this line of attack produced several seedlings which approached H 109 (Lahaina x ?) in yielding ability but none which was definitely superior. The *S. sinense* group was represented by a single variety, the so-called Hawaiian Uba. The collection contained no representatives of the *S. spontaneum* or *S. barberi* groups or of their hybrids. The wild *S. robustum* was still unknown.

Reports from Java and India of encouraging progress achieved by crossing the "noble" canes with *spontaneum* and *barberi* hybrids and quarter-breeds pointed to the desirability of trying these new blood lines in crosses with the Hawaiian varieties. However, it had not been possible to pursue this line of attack in Hawaii. The devastation wrought by the sugar cane leaf hopper which had gained entrance undetected on an importation of cuttings, probably from Australia, had led in 1904 to an embargo on the importation of cuttings from abroad, with the object of forestalling further accidental introductions of diseases and insect pests. As a result, the breeding material which was giving such promising results elsewhere was not available in Hawaii.

Interest in new breeding material led to a meeting of members of the Station staff on February 4, 1922, "to consider the introduction of foreign cane varieties into Hawaii." Present at this meeting were O. H. Swezey, Frederic Muir, H. L. Lyon, L. O. Kunkel, J. A. Verret, and H. P. Agee. It was the consensus of those present that "with adequate professional supervision and ample funds, a limited number of cane cuttings can be introduced without risk of establishing new insect pests and cane diseases." Ways and means of accomplishing this objective were discussed. It was agreed that the imported cuttings should be grown for a minimum period of one year under close supervision in specially designed quarantine houses. Regulations covering operational procedure were drawn up.

The recommendations of this group were submitted to the Experiment Station Committee, and at its meeting on February 7, 1923, the Committee voted to authorize the importation of POJ 36 and POJ 213[3]. This authorization was later extended to include POJ 234 and POJ 979. At a subsequent meeting on April 23, 1923, the Committee authorized the Director to proceed with the erection of a quarantine house to accommodate the proposed importations. The four varieties designated for importation were growing in the U. S. Department of Agriculture quarantine greenhouse at Arlington, Va.; they were inspected by Dr. Kunkel, who selected cuttings of each and shipped them to Honolulu. Upon arrival, the cuttings were again inspected by Mr. Muir and Dr. Lyon, representing the Station, and by Mr. Ehrhorn and Mr. Whitney, representing the Territorial Board of Agriculture and Forestry. The inspection committee having found no indications of foreign diseases or insects, the cuttings were planted in the newly constructed quarantine house at the Pathology Plot on Alexander Street where they

[3] POJ are the initials of Proefstation Oost Java (Experiment Station of East Java).

were grown under close scrutiny for twelve months. No evidence of disease having manifested itself by the end of the greenhouse quarantine period, the four canes were released for planting in the quarantine field. This field planting also was kept under close observation. In March 1925, the field was given a clean bill of health and cuttings were released for distribution to the plantations. This importation marks the resumption of the cane introduction program after a lapse of nearly twenty years.

Quarantine Station Transferred to Molokai

In 1928, it was decided to transfer the quarantine station to an island on which no sugar cane was being grown, the objective being a further reduction of the risk of some foreign insect or disease gaining entrance with the imported cuttings and becoming established in our sugar cane fields. A suitable site was found in an isolated area at Kanoa, on the island of Molokai, where two quarantine houses were erected upon a small plot of leased land. A five-acre tract at Kawela, several miles distant from the quarantine houses at Kanoa, was also leased for use as a quarantine field to receive cuttings of the newly imported varieties after their release from the Kanoa quarantine house.

The Kanoa and Kawela facilities were designed to handle foreign varieties imported as cuttings. In April 1929, C. E. Pemberton of the Entomology Department collected tassels of a form of *S. robustum* growing near Rabaul, New Britain. In October and November of the same year, U. K. Das of the Agricultural Department, working at the Coimbatore sugar cane breeding station in India, made a

Figure 2. In the quarantine greenhouse on the island of Molokai, imported cuttings are grown for 12 months, followed by a 12-month period of growth in a nearby field, before being released for distribution to other islands.

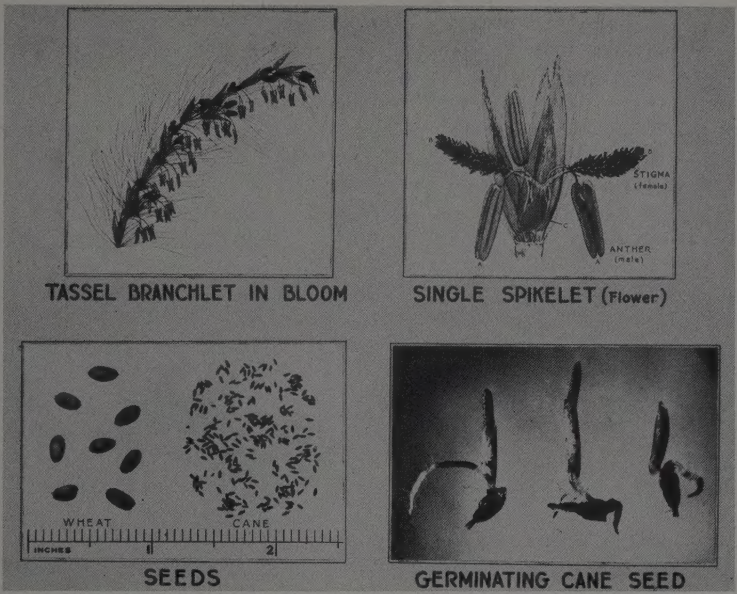

Figure 3. Sugar cane tassel, flower, seed compared with wheat grains, and newly-germinated seedlings.

number of crosses, for the most part between Indian cultivated varieties and the local form of *S. spontaneum*. The fuzz from New Britain and from India was planted in the Kanoa quarantine house. The success of this undertaking suggested that certain blood lines, particularly those of the wild species, could be imported more advantageously and with less risk if they were introduced as true seed from tassels rather than as cuttings. In 1930, two greenhouses were erected on the newly purchased Mapulehu property in East Molokai to provide quarantine facilities for the propagation of seedlings from imported fuzz (Figure 2). The first plantings in the new Mapulehu greenhouses included fuzz from crosses made in Queensland by C. G. Lennox and from tassels of *S. robustum* collected by Percy Leigh, a resident of Port Moresby, New Guinea, from the banks of the nearby Laloki River. Since 1932, all importations, both of cuttings and of fuzz, have been accommodated in the Mapulehu quarantine house.

Since the resumption of the importation program, nearly two hundred canes have been imported as cuttings and more than ten thousand seedlings have been germinated from imported fuzz. By discarding the inferior individuals, the latter group has been reduced to less than one thousand.

On the basis of its breeding performance, POJ 2878 must be rated as the most valuable of the breeding canes thus far introduced. It was released from quarantine in 1929. POJ 2878 is a parent of 32–8560 and of 32–1063; it is a grandparent of 37–1933 and of many other promising seedlings. As the mother of 32–8560, Co. 213[4] also deserves honorable mention. The *robustum* importation finds its justifica-

[4] Co. is an abbreviation of Coimbatore, a town in southern India near which the Indian sugar cane breeding station is situated.

tion in 37–1933, of which the Port Moresby *robustum* is a great-grandparent. It appears likely that other *robustum* derivatives will play an increasingly important role in future breeding.

In retrospect, we can appreciate the misgivings which attended the decision to reopen the doors to foreign introductions. Hawaii had remained free of several sugar cane diseases that had caused serious losses in other countries. The importation of new canes from abroad inevitably entails a certain risk; there is always the possibility that a foreign cane, however healthy its appearance, may carry a dangerous disease in a latent form. The decision to resume the introduction of breeding material was made under the firm conviction that the prospective gains were great enough to justify the risk. The wisdom of this decision has been established by its outcome.

BREEDING PROCEDURES

Early Crossing Methods

In the early days of sugar cane breeding, the seedlings were for the most part derived from open-pollinated tassels, usually collected from situations where the desired female parent was growing in close proximity to acceptable male-fertile (pollen-producing) varieties (Figure 3).

A subsequent refinement consisted in cutting tassels of the variety which was to serve as the male parent, placing these cut tassels in vases of water and supporting them in position around the female tassel which was left in place in the field. Sometimes the female and male tassels were enclosed with a cloth hood or "lantern" (Figure 4) to reduce the likelihood of contamination by foreign pollen. This procedure was at one time widely used in Java. In Hawaii, however, it was found that tassels enclosed in lanterns yielded fewer seedlings than did those ripened in the open; in Java the use of the lantern was eventually restricted to crosses in which certainty of parentage was of paramount importance. In Formosa, in Barbados, and in Mauritius, the lantern method is still widely employed.

The sugar cane tassel requires from five to ten days to complete its blooming (Figure 5). The flowers near the tip of the tassel bloom first, the course of blooming proceeds downward day by day toward the base of the tassel. The tassels of the male parent, even though placed in vases of water, rarely bloom normally for more than a day or two after cutting. It was, therefore, necessary to replace the male tassels daily with freshly cut tassels. The high labor requirement of this procedure thus limited the number of crosses that could be completed during the short tasseling season.

Development of Sulphurous Acid Crossing Technique

It was recognized that crossing would be greatly expedited if some means could be found to prolong the life of the cut male tassels, thereby obviating the necessity of replacing them each day. In 1924, J. A. Verret in collaboration with Y. Kutsunai, U. K. Das, Raymond Conant and Wm. Twigg-Smith, embarked upon a program of experimentation in this direction. In 1925, they were able to report the attainment of their objective. "After conducting a large number of experiments (one hundred or more) with all kinds of preservatives and other solutions we found that by placing the cut end of a cane stalk, with or without a tassel, in a solution

Figure 4. Lanterns were used in making crosses before the advent of the sulphurous acid technique.

Figure 5. Tassels are cut for crossing when the blooming has proceeded several inches downward from the tip of the panicle.

of sulphurous acid (SO_2), 1 part in 2000, it will keep alive, in apparently normal condition, for several weeks."[5]

To the surprise and satisfaction of all concerned the solution proved so effective in keeping the cut stalks alive that they were able not only to complete their blooming and pollen shedding in a normal manner, but also to mature their seed. Thus it became possible, in making crosses, to cut both the female and the male tassels and place them together in an isolated situation well removed from danger of contamination by wind-borne pollen, with the cut ends of their stalks standing in a pail of the SO_2 solution.

Much of the experimentation which led to this achievement was carried out by the late Dr. Das, who was at that time an undergraduate student at the University of Hawaii. In reporting these findings Mr. Verret says: "In this work Mr. Das has shown resourcefulness and initiative and deserves great credit for the results obtained."

Although some varieties lived quite well in the sulphurous acid solution, others tended to die prematurely. From 1928 to 1931 during the tasseling seasons further experimentation was carried out with the object of finding means of enhancing the effectiveness of SO_2 solution. Many members of the Station staff, including C. W. Atkinson, H. F. Duncan, A. H. Cornelison, and Rokuro Urata, participated in this work.

It was found that weak solutions of a number of acids, such as nitric, nitrous, sulphuric, phosphoric, and hydrochloric, have in common with sulphurous acid the ability to promote the maintenance of turgidity in the cut stalks. The details of the physiology of this effect are as yet unknown; we must look to the biochemists for an explanation of the phenomenon.

A combination of phosphoric and sulphurous acids eventually proved to be superior to sulphurous acid alone. This mixture was therefore adopted as the standard medium. The modified sulphurous acid solution as now employed contains 150 ppm of SO_2 and 85 ppm of H_3PO_4. In practice, stock solutions of known concentration are made up and diluted to the proper strength. The strength of the diluted solution is checked by titration (Figure 6).

With their cut ends immersed in this solution, the tassels of most varieties complete their blooming in a normal manner and continue to remain alive until the seed has ripened, a period of three to four weeks from the commencement of blooming.

For best results the tassels must be cut with several feet of mature stalk; if the supporting stalk is too short the tassel will die prematurely. The solution must be changed at regular intervals. Present practice calls for complete replacement with fresh solution twice weekly, and for replenishment on intervening days.

The sulphurous acid method has not been generally adopted by sugar cane breeders in countries which have an abundant supply of cheap labor. Where labor is costly, the method offers important advantages. In Hawaii, it has made possible the completion of more than five hundred crosses during the six-week crossing season with no more labor than would be required for a hundred crosses under the old procedure, which necessitated daily replacement of the male tassels.

The sulphurous acid method permits the breeder to set up his crosses in isolated situations well removed from danger of contamination by wind-borne pollen,

[5] The Hawaiian Planters' Record, Vol. 29, pp. 84–94. 1925.

Figure 6. Titrating sulphurous acid solution to determine the concentration of SO_2. The final solution contains 150 ppm SO_2 and 85 ppm H_3PO_4.

thus reducing the element of doubt as to the paternity of the resulting seedlings. The method is particularly valuable in the case of varieties which seldom tassel; the rare tassels of such varieties, if male-fertile, can be used to pollinate a much larger number of female tassels than was possible under the old procedure.

The importance to Hawaii of this development can be appreciated from the fact that, since 1931, every seedling of commercial value has been derived from crosses of which one or both parents were kept alive by means of the modified sulphurous acid solution.

Melting Pot Crossing

In addition to the conventional bi-parental crossing which involves the mating of two parent canes in isolation, two techniques have been developed in Hawaii with the object of producing seedlings from a large number of combinations at minimum expense. The considerations supporting these techniques, the "melting pot" and the "area cross" are discussed in another paper.[6]

Briefly, the melting pot is an area to which is brought a wide diversity of highly selected female (non-pollen shedding) varieties (Figures 7–10). In this area, interspersed among the female tassels, are placed tassels of a number of elite male (pollen-shedding) varieties. The tassels in the melting pot are shuffled periodically with the object of increasing the randomness and diversity of cross-pollination. Only the female parent of progeny from the melting pot is known. However, it is also known that the male parent was one of a highly selected group of breeding canes.

In addition to the large general melting pot, smaller melting pots are set up for special purposes. A mauka[7] melting pot, for example, provides opportunity for

[6] The Evolution of a Philosophy on Sugar Cane Breeding in Hawaii, elsewhere in this issue of the Hawaiian Planters' Record.

[7] "Mauka" is an Hawaiian term meaning "toward the inland." The opposite term is "makai," meaning "toward the sea." In comparison with the makai areas, the mauka areas are characterized by higher elevations, lower temperatures, higher rainfall, less sunlight and poorer soils.

Figure 7. A tassel is examined with a hand lens to determine whether the anthers are shedding pollen (males) or whether they are sterile (females).

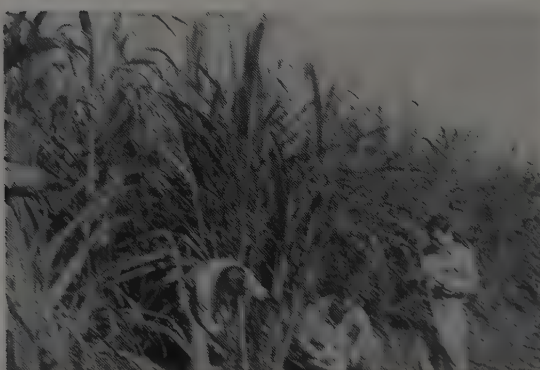

Figure 8. Individual tassels are cut and tagged for the mating pot.

Figure 9. Cut tassels, standing in waiting racks at the edge of the fields, are picked up by trucks or trailers fitted with watering tanks and backboards to support them in transit.

Figure 10. Newly-cut tassels are distributed in the melting pot. The tassels will be shuffled twice a week to insure random pollination.

Figure 11. Racks of tassels in the ripening area.

Figure 12. Harvesting a ripe tassel in the ripening area.

parents which are especially adapted to mauka conditions to cross among themselves.

Area Crossing

The "area cross" is one in which a single outstanding male parent is used to pollinate a number of female varieties. As in the bi-parental cross, both parents of the progeny will be known. Because they can be serviced more efficiently, area crosses are less costly than bi-parental crosses. However, the usefulness of this method is limited by the fact that only female parents which produce no pollen can be admitted to the area.

The Ripening Area

When the tassels in the various isolation racks and in the melting pot areas have finished their blooming, they are transported to a central ripening area, where they can be serviced more conveniently and where they can be watched closely so that they may be harvested at the proper stage of maturity (Figures 11 and 12). Upon removal of the female tassels in the bi-parental and area crosses from the isolation racks to the ripening area, the male tassels are discarded. All tassels in the melting pot areas, both male and female, are transported to the ripening area and are harvested for subsequent sowing.

GERMINATION AND CARE OF SEEDLINGS

Greenhouse Procedures

The early sugar cane breeders were handicapped by a lack of adequate greenhouse facilities. A cross between two varieties having been achieved at the expense of much time and effort, it frequently happened that many of the resulting seed-

Figure 13. Seedling propagation area in 1927.

Figure 14. In newly-germinated flats, a *PYTHIUM* infection can spread rapidly, leaving few survivors in its wake.

lings perished in the germinating flat for want of adequate protection from the elements.

Since the fuzz planting season falls in the winter months, high winds, heavy rainfall, and low temperatures are likely to be encountered. In former years, newly germinated seedlings sometimes died by the thousands during spells of bad weather (Figure 13). This difficulty was met, in 1928, by the erection of a large modern greenhouse on the Experiment Station grounds at Makiki. Favorable conditions for germination can be maintained within the greenhouse regardless of outside weather conditions.

In the past, *Pythium* root rot caused heavy losses in the seedling flats. Once the seedlings have developed a fairly extensive root system, the resistant individuals are able to survive in the presence of the fungus. In their infancy, however, sugar cane seedlings are highly susceptible to *Pythium* root rot. The fungus sweeps across a flat of newly germinated seedlings leaving but few survivors in its path (Figure 14).

Steam sterilization affords an effective means of eliminating the *Pythium* fungus from the soil. From the surplus stockpile of World War I, the Experiment Station acquired a battery of army "delousers." Each of these large autoclaves can accommodate 50 soil-filled flats;[8] each charge is sterilized for two hours at 15 pounds pressure. From the autoclave, the sterilized flats go directly to the greenhouse for planting.

Unless suitable precautions are observed, the sterilized flats in the greenhouse may become recontaminated with *Pythium*. Sanitary measures, such as rinsing the hands in a Lysol solution upon entering, have reduced the incidence of *Pythium* within the greenhouse to a low level.

In recent years, the incidence of *Pythium* infection in the seedling flats has been further reduced by periodical applications of a Phygon[9] drench, following a procedure developed by J. P. Martin in 1948.

[8] The standard germinating flats, constructed of wood, are 14 x 20 inches with a depth of 4 inches.

[9] Phygon is the trade name for a fungicide containing 2,3 dichloro- 1,4-naphthoquinone. The drench is applied to the seedling flats bi-weekly at the rate of one gram of Phygon (50 per cent active ingredient) suspended in a pint of water per square foot of area.

Figure 15. Stripping fuzz from a dry tassel.

Figure 16. Screening the soil-compost mixture with the aid of a power pulverizer. The men at the left are filling flats with the screened mixture.

Figure 17. The unsterilized flats are loaded into autoclaves for sterilization.

Figure 18. The fuzz-planting crew at work. The wooden frame fitting over the flat prevents air currents from carrying fuzz into neighboring flats.

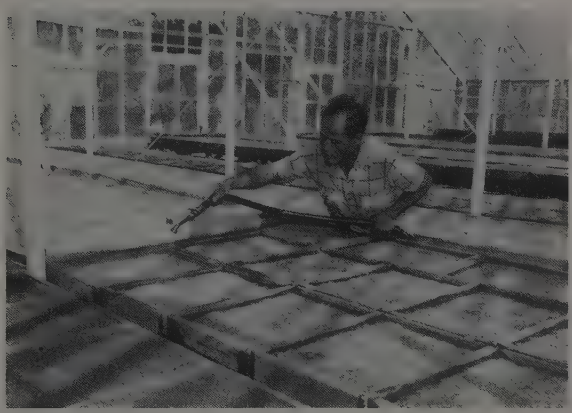

Figure 19. Watering the newly-planted flats. Note the rolls of wax paper with which the flats are covered until germination is well under way.

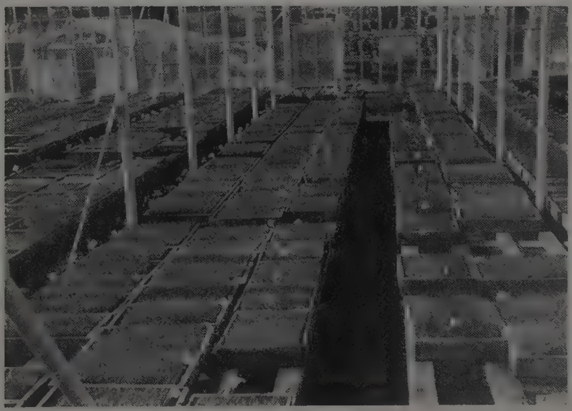

Figure 20. The greenhouse, almost full of newly-germinated seedlings.

Still another development in greenhouse practice is the use of wax paper for covering the flats during the germinating period. An entire table of newly-sown flats is covered from end to end with a single strip of this paper, which serves to maintain favorable conditions of temperature, humidity and soil moisture at the soil surface. The wax paper is removed at the onset of germination which usually takes place four or five days after planting. This development was contributed by C. C. Barnum in 1925.

The combined benefits of these several developments have resulted in a great reduction in mortality of seedlings in the germinating flats (Figures 15–20).

Transplanting

When the rate of germination in the original flat happens to be exceptionally heavy or when a higher survival rate is desired, the seedlings when one to three inches tall, are transplanted in bunches of 5 to 15 seedlings each, to other sterilized flats. Each flat accommodates thirty "bunches" or a total of 300 to 500 seedlings. Thus one original germinating flat containing several thousand seedlings may be expanded by bunch transplanting to three or more flats (Figure 21).

Seedling populations resulting from crosses of special interest may be "space transplanted" to insure maximum survival. Under this procedure, the seedlings, transplanted individually, are spaced two inches apart. A flat so planted accommodates 48 seedlings. In transplanting from such a flat to the field, the individual seedlings are spaced from 12 to 18 inches apart in the row. Space transplanting in flats has proved more efficient than the old procedure of transplanting to individual pots.

Shipping to Other Islands

Quarantine regulations prohibit the transport of unsterilized soil from Oahu to the other islands. In the early years of sugar cane breeding, the seedlings were germinated in nurseries situated on each island.

With the development of specialized greenhouse facilities at the central nursery at Makiki, nurseries on the neighboring islands were discontinued. Seedlings destined for these islands were germinated in the Makiki greenhouse and held in pots or "transplant" flats in the outdoor nursery until they had grown to a height of 12 to 18 inches and were ready for transplanting to the field nursery.

To comply with the quarantine regulations, it was necessary, when shipping seedlings, to remove all soil from the roots by washing them under a stream of water. The seedlings of each cross were then bundled separately with their roots packed in moist sphagnum moss. Upon arrival at their destination, the seedlings were planted in the field nursery as promptly as possible.

This procedure involved several disadvantages: it was time-consuming, and it so aggravated the transplanting shock that a considerable percentage of the seedlings failed to survive.

The procedure now employed was adopted some ten years ago. As a first step, the greenhouse was screened to exclude the Anomala beetle against which the soil quarantine is directed. Soil-filled flats are permitted to enter the greenhouse only after steam sterilization.

In four to six weeks after germination, the seedlings are large enough to leave the greenhouse and are ready for shipment. Their leaves are first trimmed lightly

to reduce transpiration in transit. The flat of seedlings is then covered by an inverted empty flat of the same dimensions. The cover is held firmly in place by a tightly-cinched steel strap (Figure 22). As a safeguard against damage en route, the flats are stacked on skips, on which they remain until they reach their destination.

Upon arrival at the regional stations, the covers are removed and the flats are placed on tables in an outdoor nursery, where the seedlings are permitted to grow for another month or two before transplanting to the field nursery.

The Outdoor Nursery

After removal from the greenhouse when they are four to six weeks old, the seedlings are cared for in an outdoor nursery until they have grown strong enough to survive transplanting to the field nursery. This requires from four to eight weeks, depending upon the vigor of the particular population of seedlings (Figures 23 and 24).

During their stay in the outdoor nursery, the seedling flats are given a bi-weekly application of an NPK nutrient solution, and a bi-weekly Phygon drench to control *Pythium*. For convenience the Phygon may be combined with the nutrient solution in a single bi-weekly application. The leaves of the seedlings are trimmed lightly at ten-day intervals to prevent lodging in the flats. A final trimming is given just before transplanting to the field nursery (Figure 25).

The Field Nursery

As we have seen, the task of making crosses and of propagating seedlings was fraught with many difficulties in the early days of sugar cane breeding. Since new seedlings were not easy to come by, they were not to be discarded lightly. Neither effort nor expense was spared to make sure that every surviving seedling should have a fair chance to prove its worth.

Improvements in crossing and in nursery techniques have made it possible to propagate seedlings from desired crosses in large numbers at a greatly reduced cost per seedling. With thousands of additional seedlings from promising combinations to be had at little additional expense, the need for efficiency in testing becomes paramount. The program must be ruthlessly purged of all non-essential details which would tend to limit the number of seedlings that can be effectively tested. Some progress has been made in this direction.

Formerly each seedling was transplanted from its germinating flat to an individual pot. When the seedlings had grown in the pots to a height of a foot or two, they were transplanted to the field. Here they were spaced from two to four feet apart in the row to give each seedling from 8 to 20 square feet of space. An acre thus planted could accommodate from 2000 to 5000 seedlings.

Under the present "bunch planting" procedure, the seedlings are transplanted directly to the field from the original germinating flats, or from bunch-transplanted flats, in bunches of 5 to 15 seedlings, each bunch occupying from 3 to 10 square feet, depending upon the spacing between rows and between bunches in the row (Figure 26). The spacings between bunches in the row and the number of seedlings per bunch are determined by the interest in the particular cross and by the area available. An acre of bunch plantings thus accommodates from 40,000 to 100,000 seedlings.

Figure 21. Bunch transplanting of seedlings in the greenhouse.

Figure 22. Packing and sealing flats of seedlings for shipment to neighboring islands.

Figure 23. Seedling flats are being shifted from the greenhouse to the hardening-off area.

Figure 24. The hardening-off area where the seedlings become accustomed to the elements.

Figure 25. Trimming the leaves of the seedlings in the hardening-off area to promote maximum survival.

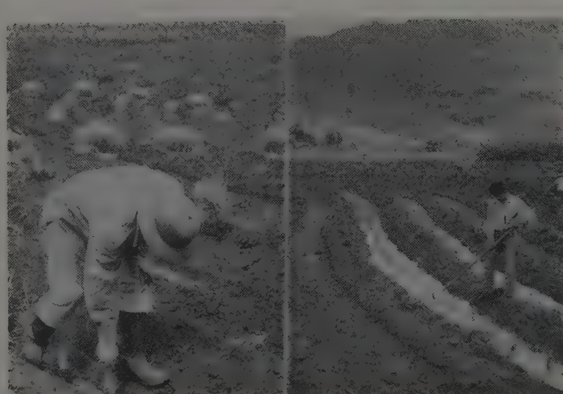

Figure 26. Bunch plantings are set out in the field nursery. After the plants have been covered, the field is irrigated.

The rate of elimination by natural selection in such a planting is high. Those seedlings which are fortunate enough to get off to a fast start and those which are above average in vigor enjoy a competitive advantage. By selection time at 10 to 12 months of age, a considerable proportion of the original number will have succumbed to competition from their neighbors, leaving 30,000 to 40,000 survivors per acre, each represented by a single stalk. Under the intense competition which prevails in such a planting, tillering to produce secondary stalks can occur only rarely.

The conversion to the bunch planting procedure has been a gradual one. Bunch plantings were first tried on an exploratory scale in 1935, utilizing for this purpose remnant seedlings from flats which had produced more seedlings than could be accommodated in the then standard spaced plantings of individual seedlings. The bunch method was regarded at first with skepticism; it was felt that this procedure would favor the selection of rank growing, low sucrose canes at the expense of high sucrose canes. These misgivings, however, have not been borne out; the sucrose ratings of the seedlings selected from bunch plantings have not averaged significantly poorer than those of the seedlings selected from space plantings. 37–1933, a high sucrose cane, was selected from a bunch planting of remnant seedlings left over in a flat from which the space planting quota had previously been removed. Under a strict space planting program, these "extra" seedlings would have been consigned to the compost heap.

During World War II, as labor shortages became more and more stringent, it became necessary either to curtail the breeding program drastically or to confine the work to procedures having a low labor requirement. By utilizing the melting-pot crossing technique and the bunch planting procedure, it was possible to maintain the volume of seedling propagation throughout the war years at a level close to that of the pre-war period.

Even the most outstanding crosses produce only a small percentage of seedlings having commercial possibilities. The overwhelming majority of the original populations of unselected seedlings are worthless for one reason or another. The bunch planting method accomplishes an early elimination of much worthless material at a minimum expenditure of space and effort. Thus, with a given staff and a given area, it is possible by means of this method to carry a much larger population of seedlings through the first field nursery than could be handled under the conventional space planting procedure.

Other things being equal, the chances of finding a superior new cane are proportional to the number that can be tested. Any modification that can increase the capacity of the existing facilities merits consideration. Under conditions of high labor cost, the bunch planting procedure offers substantial advantages.

SELECTION IN THE BUNCH NURSERY—The original nursery plantings are selected when a year old. Selection consists in examining those seedlings which have produced a better than average stalk, and in retaining those which, being free from obvious faults, appear worthy of further testing. The number selected ranges from 1000 to 2000 seedlings per acre of bunch nursery. A normal season's field nursery planting of 20 to 30 acres will yield from 20,000 to 50,000 seedlings for "5x3" testing. From each seedling selected in the bunch nursery, two 18-inch cuttings are taken for planting in the 5x3 stage.

THE "5x3" STAGE—In this stage, the two 18-inch cuttings from the nursery are planted side by side in the furrow with the eyes pointing in opposite directions. Each seedling is allotted three feet of row, half of which is occupied by the 18-inch cuttings, the other half by an 18-inch space which separates it from the next seedling in the row. The rows are usually five feet apart and each seedling occupies three feet of row, hence the 5x3 designation.

Selection in the 5x3 planting is based upon notes taken during the growth of the crop and upon the appearance of the seedling at twelve months. The identification of the individual seedlings for note-taking is facilitated by a systematic placement of check plots. Every fifth plot in the row is a check plot of the leading commercial variety of the district. Each row in the field and each check plot in the row are numbered consecutively. Thus the check plots in Row 1 are numbered 1x1, 1x2, etc., those in Row 2 are numbered 2x1, 2x2, etc. The four seedlings which follow a given check plot are identified as A, B, C and D. Thus 13x7C refers to the third seedling beyond Check Plot No. 7 in Row 13.

Up to this point the seedlings have not yet received their permanent individual numbers; each seedling is identified both by its "family" or "cross" number which is the number originally assigned to the tassel or tassels from which it was germinated, and by its location in the 5x3 planting. All seedlings selected in 5x3 for advancement to the "5x6" stage are assigned permanent numbers, each number consisting of two parts, viz., the year planted in 5x3 and the serial number. Thus seedlings selected from 5x3 in the spring of 1952 were numbered 51–1, 51–2, 51–3, etc.

The per cent selected from the 5x3 stage for further testing ranges from zero to twenty or more, according to the vigor and general attractiveness of the individual seedlings in the lot. From a population of twenty to fifty thousand in the 5x3 stage, some three to six thousand seedlings are selected and distributed among the regional stations for 5x6 testing.

THE "5x6" STAGE—In the field nursery, each seedling is represented by only a single stalk; in the 5x3 stage, by only a single three-foot plot. Thereafter, however, an approach toward replication is achieved by sending the seedlings selected from 5x3 to more than one regional station for 5x6 testing. Each selected seedling is sent to at least one windward (unirrigated) and one leeward (irrigated) regional station; a seedling which appears particularly promising is sent immediately to as many stations as the seed supply permits. The 5x6 stage differs from the 5x3 stage in plot size, the length of row having been increased to six feet.

In the 5x6 stage, selection is based upon notes taken periodically during the growth of the crop, upon juice quality, and upon appearance at twelve months of age. Since the seedling is now under test at several regional stations, the selector has the benefit of additional guidance from notes and Brix[10] readings recorded at these several stations. At selection time, a seedling which continues to show promise is advanced to the "10x15" stage; it is also sent for 5x6 testing to appropriate stations which have not yet received it.

Of the three to six thousand seedlings which each year enter the 5x6 stage of testing, some three to five hundred are selected for advancement to the 10x15 stage.

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[10] Brix is a measure of total solids in solution in the juice; it is closely and positively correlated with per cent sucrose.

THE "10x15" STAGE—In this stage, a plot consists of two adjacent rows, each 15 feet long. As in the preceding stages, every fifth plot is a check plot of the standard variety. By selection time at twelve months of age, a considerable body of information concerning each seedling in the 10x15 stage will have been assembled in the Master File which is maintained in the Genetics Department office. As indicated by its name, the Master File is a complete record of seedling performance. When a selected seedling receives its permanent number, it is assigned a separate page in the Master File. Upon this page are entered all gradings, observations, Brix readings, and yield data recorded for that particular seedling from each of the regional station and plantation fields in which it is being tested.

With the information from the Master File at his disposal, the selector is guided not only by the appearance and juice quality of the seedling in the particular planting under examination; he has before him also a "field ledger," a record of such notes as had been previously made of that planting, together with a summary of Brix determinations from other plantings and of observations under other conditions.

Of the three to four hundred seedlings which each year enter the 10x15 stage, some fifty to one hundred are selected for advancement to the "30x30" stage.

THE "30x30" STAGE—In this stage, a plot consists of six parallel and adjacent rows each 30 feet long; each plot thus comprises about one-fiftieth of an acre. Every fifth plot, or, in areas of variable soil, every third plot, is a check plot of the standard variety.

The 30x30 stage of testing is a critical one in the career of a new seedling. In this stage, it is carried for the first time through a two-year crop[11]. This stage provides for the first time quantitative data in terms of tons of cane and tons of sugar per acre at harvest. It also provides the first opportunity to judge the ratooning ability of the new seedlings under two-year cropping in plots large enough to minimize the border effect of neighboring varieties.

In many varieties of sugar cane, the individual stalks have pronounced annual tendencies; they grow vigorously only during their first year. Thereafter growth diminishes or ceases, whereupon the stool sends out a flush of second-season suckers which in turn grow vigorously, while the first-season stalks, now entering upon their second year, stagnate and eventually die. Such a variety, however outstanding it may have been at twelve months, is no longer in the running when harvested at 24 months. To qualify as a commercial variety under our two-year cropping practice, a seedling must be able to maintain growth in its original population of stalks and to carry them through a two-year period in sound condition.

Of the many seedlings which enter the 30x30 stage of testing, only a few can approach the present standard varieties in sugar yield when harvested at two years of age. Among these few must be sought the future commercial varieties of the industry.

SEEDLING EVALUATION

Selection Criteria

Because of the relatively large error inherent in small unreplicated plots, no attempt is made to weigh the cane produced in the 5x3, 5x6, and 10x15 plots. Selection in these early stages of testing is based upon the health, vigor and other

[11] In Hawaii the age of the crop at harvest approximates 24 months.

visible characteristics of the seedlings, and upon sucrose content as estimated from refractometer readings. Some of the more important selection criteria are listed below.

1. *Sucrose content*—Most of the present major varieties are well above average in sucrose content. A new seedling which falls too far below par in this respect cannot qualify as a commercial variety.

2. *Growing power*—Tonnage of sound cane at harvest is the resultant of the growing power of the seedling and its ability to "carry over." Weed controlling ability is also a function of growing power. As indicated above, many seedlings grow vigorously enough through the first year; at the beginning of the second season, however, they tend to develop a flush of sucker growth at the expense of the first-season stalks which then stop growing and eventually die. Capacity for sustained second-season growth of the initial stalk population is important under our long-cropping practice.

Rate of elongation is only one of the several components of growing power. Ample tillering and adequate stalk diameter are equally important.

3. *Freedom from tasseling*—Fields that tassel heavily during their first year are often disappointing in sugar yield. Tasseling is not a serious problem in the hot sunny lowlands of the leeward districts nor in the uplands at elevations above 1500 feet; under these extreme conditions most varieties produce few or no tassels. In some districts, however, tasseling may reach such serious proportions that many seedlings which are attractive in other respects must be discarded. The development of good lalas (side shoots) after tasseling is to be desired, but because of their constricted attachment to the main stalk lalas are at best a poor substitute for the original top. The more vigorous the lala and the heavier it becomes, the more liable it is to be broken off by high winds.

4. *Toughness*—This term refers to the ability of stalks to lodge without snapping or fracturing. Under 24-month cropping, all first-season stalks must eventually lodge; if the stalks are brittle, they are likely to snap off partially or completely at the base when the crop lodges. Toughness appears to have an important bearing upon condition of the crop at harvest and thus upon juice quality.

5. *Hardness*—Seedlings which are extremely soft are vulnerable to damage by borers and rats; those which are extremely hard are likely to be too high in fiber and therefore too low in percentage of recoverable sugar. The successful commercial varieties are intermediate in fiber content.

6. *Juiciness*—A considerable proportion of the seedlings of *robustum* and *spontaneum* derivation are too pithy to qualify as commercial varieties. Seedlings with pithy stalks tend to be unduly high in fiber content.

7. *Leaf system*—Under good growing conditions, canes with a heavy leafy top tend to be self-composting, a condition that results in poor burns and in unduly high percentages of dead cane and trash at harvest. Canes with clinging leaf sheaths are particularly objectionable in this respect.

8. *Drought resistance*—Lack of adequate soil moisture acts as a limiting factor in many areas, particularly during the summer months. Seedlings that are unduly susceptible to the effects of drought cannot qualify as commercial varieties in such areas.

9. *Disease resistance*—Among the recognized and identified diseases affecting sugar cane in Hawaii, the most important are leaf scald, *Pythium* root rot, mosaic,

chlorotic streak, eye spot, and brown stripe. A seedling which evidences undue susceptibility to any one of these diseases is disqualified as a commercial variety for those districts where that particular disease is likely to prove serious.

Testing for Disease Resistance

In selecting sites for the stations in the regional variety station network, the chief aim has been to provide representation of the major ecological conditions under which sugar cane is grown in the Islands. Insofar as this aim has been realized, the regional station network provides a good opportunity for evaluating the resistance of the new seedlings to the various components of the pathogen complex with which a commercial variety must contend in the field. There remains the possibility that a new pathogen, or a new race of a long established pathogen, may not yet have reached any of the variety stations in the network. In such an event, susceptibility to a new or rare pathogen may not become apparent until the seedling reaches the plantation stage of testing.

During recent years, the coverage of the range of conditions in the various cane growing districts has been greatly improved by the participation of the plantations in the 10x15–30x30 testing program. Maintenance of the plantation program at a high level will help to insure prompt recognition of undue susceptibility not only to the recognized diseases, but also to those that still remain to be identified.

The Pathology Department cooperates with the Genetics Department in conducting special tests to ascertain the resistance of the more promising seedlings to certain of the known diseases such as leaf scald and chlorotic streak.

In 1946, the HSPA established in American Samoa a substation for the study of Fiji disease. Although this disease does not occur in Hawaii, its presence in Samoa, Fiji, Queensland, and the Philippines, poses a continuing threat in view of the expanding air traffic between these regions and Hawaii. The danger is aggravated by the fact that the leafhopper vector is already present in Hawaii.

Early in 1952, the Samoa station was closed out. The testing activities were transferred to Fiji where a project has been initiated in cooperation with the Colonial Sugar Refining Company. In the new site it will be possible to test for resistance to downy mildew as well as to Fiji disease.

During its five-year period of activity, the Samoa station was able to determine the degree of susceptibility of all of the commercial varieties, of some of the more important breeding canes, and of a large number of the promising newer seedlings. Of the present commercial varieties, only 39–3633 proved resistant to Fiji disease. 37–1933 is classed as moderately resistant. Many of the seedlings of *robustum* and *barberi* derivation were found to be resistant and these canes are being used as parents to incorporate resistance into the commercial varieties of the future.

Preliminary Testing for Sucrose Content

The problem of ascertaining whether a new seedling is above or below average in sucrose content would seem at first glance to be a simple one, but such is not the case. The difference in sucrose content in different portions of the same stalk and between stalks of the same variety results in a high coefficient of variation. Sucrose determinations are thus liable to a high sampling error. Adjoining plots

Figure 27. Drawing a punch sample of juice and reading its Brix with a hand refractometer.

of a single variety may differ materially in sucrose content. It follows that conclusions based upon only one or two analyses may be in error. For reliable conclusions as to whether a new seedling is better or poorer in juice quality than the standard variety, many replications are needed.

With thousands of seedlings to be tested each year for sucrose content, laborious and time-consuming procedures are out of the question. The cane breeder is fortunate in having, in the hand refractometer, a simple and direct means of estimating the sucrose content of small samples of juice (Figure 27).

Use of the refractometer to estimate the juice quality of new seedlings finds justification in the high correlation connecting refractometer Brix with purity and with yield per cent cane. These correlations have been established by many studies at this Station and elsewhere.

In sampling the plot for a refractometer reading, a composite juice sample is drawn by "punching" every stalk in the plot if the plot is small; in larger plots, 20 or more stalks are sampled. For comparison, similar samples are drawn from the nearby check plots of the standard variety.

By the time a seedling has passed through its course of testing at the regional stations, some fifteen or more Brix determinations on that seedling will have been recorded in the Master File. Each determination is accompanied by a corresponding check figure arrived at by averaging the Brix readings from nearby check plots of the standard variety. The following example shows how the Brix tallies from the Master File may be used in rating new seedlings:

Seedling Number	Number of Determinations		
	Better than Check	Equal to Check	Poorer than Check
49–722	10	2	0
49–907	0	1	9
49–2089	3	6	4

From such a set of figures, it is possible to classify the seedlings in respect to their Brix tallies. In the above example, seedling 49–722 has a good Brix tally, 49–907 has an extremely poor tally, while 49–2089 is only average.

The sampling procedure as outlined above is employed only in preliminary testing up to and including the 10x15 stage. Analyses of juice samples from the 30x30 stage and from final replicated tests include polarization as well as Brix determinations.

It should be pointed out that the Brix tally, based as it is upon samples drawn from year-old cane, cannot be expected to afford a wholly reliable indication as to how the seedling will rank in terms of tons cane per ton of sugar under two-year cropping. Many of the canes that have good Brix tallies at twelve months of age prove to have poor Quality Ratio[12] tallies at 24 months due to their inability to carry through in sound condition under long cropping. Conversely, some canes that have poor Brix tallies at twelve months come through with better than average Quality Ratio tallies under 24-month cropping, due to the ability of their stalks to maintain themselves in sound condition and to increase in sucrose content with increasing age. It would be unsafe to discard an otherwise highly desirable seedling merely because its Brix tally at twelve months happened to be below average.

Bud Selection

In 1920, the industry embarked upon a program aimed at selecting superior subclons of the principal varieties of that period. The work of A. D. Shamel, of the U. S. Department of Agriculture in selecting subclons within citrus varieties had attracted considerable attention and Mr. Shamel's services were retained by the Station on a part-time consulting basis. Subclons of H 109, Yellow Caledonia, and D 1135 were selected in large numbers on the plantations and a program of testing was instituted with the object of identifying superior lines.

The interest in bud selection during the early 1920's is understandable when it is remembered that the breeding program up to that time had failed to uncover a single individual among the thousands of new seedlings tested that was definitely superior to H 109 or Yellow Caledonia, the leading varieties of that period. It is understandable that under these circumstances any possible means of improving yields should receive consideration.

The new and striking successes of the sugar cane breeding programs of Java and India, which began to attract attention soon after the initiation of the bud selection program, resulted in a revival of interest in breeding. The Station succeeded in 1923 in obtaining seedlings of Uba. In 1925, seedlings were germinated for the first time from tassels of Yellow Caledonia. In 1925 also, the first of the

[12] Quality Ratio is a calculated estimate of the number of tons of cane required to produce one ton of sugar. Calculations are based upon Brix and purity of crusher juice, assuming a uniform fiber content. For seedlings that are materially above or below average in fiber content the Quality Ratio figure may involve a considerable error.

new importations of breeding canes were released. Under the impact of renewed activity in breeding, interest in bud selection began to lag. By 1930, the bud selection program had all but disappeared from the plantation scene.

Soon after the inauguration of the bud selection program in sugar cane, the pineapple industry became interested and some of the companies embarked upon a similar program. The bud selection program in pineapples helped to reduce the incidence of certain easily recognizable defective types, such as "collar of slips." One of the companies succeeded in isolating several superior subclons of the Cayenne variety which have since been spread to extensive areas.

The Regional Variety Stations

The sugar cane lands of these Islands embrace a wide range of soil and climatic conditions. The windward slopes are characterized by heavy rainfall and deficient sunshine; the leeward slopes by low rainfall, abundant sunshine, and relatively high temperatures. Between these extremes are transition regions with intermediate conditions. The sugar cane fields extend from sea level to elevations of more than two thousand feet. Rainfall increases with increasing elevation, while sunshine and temperature diminish. These climatic changes are accompanied by changes in soil type.

The lower lands of the leeward slopes require intensive irrigation. The higher lands and the windward slopes may receive irrigation only during dry weather or they may depend entirely upon rainfall for their moisture.

In view of the diversity of soil and climatic conditions, it is not surprising that a variety well suited to one district may fail in another district. The goal in sugar cane breeding is to develop, for each district, varieties which are adapted to the conditions of that district.

When seedling propagation was first initiated in 1904, the Station had no facilities for testing the new seedlings other than those afforded by the small plots adjoining the Station headquarters at Makiki. The establishment in 1911 of a 130-acre station at Waipio provided ample area for the testing of seedlings, but this station was representative only of the lowland leeward irrigated conditions.

In the Report of the Experiment Station Committee for 1919, page 6, we read that "By purchase, we acquired 120 acres at the head of Manoa Valley. Some 30 acres of this land are suitable for sugar cane seedlings." This acquisition provided for the first time a testing area under cloudy upland conditions. Y. Kutsunai was placed in charge of the Manoa Substation. It is of interest to note that 32–1063, for many years a leading variety in the Hilo District, underwent its preliminary testing at the Manoa Substation. With the establishment of regional stations in the windward districts, seedling testing at Manoa was discontinued in 1934 and the cane fields were given over to forestry plantings.

The Kailua Field Laboratory was established in 1926, with H. K. Stender serving as its superintendent from the time of its inauguration until his transfer in 1938 to Kauai as Island Representative. Situated on the windward side of Oahu, the Kailua Station provides climatic conditions which favor heavy tasseling, a major consideration in selecting a site for a breeding station.

In the early years of sugar cane breeding in Hawaii, the newly propagated seedlings were frequently sent from the germinating nursery directly to the plan-

tations with no screening whatsoever. This procedure afforded certain advantages, but it imposed a burden which the plantation organization was sometimes unable to handle effectively. As time went on, it became increasingly apparent that a network of regional variety stations was needed to handle the preliminary testing for the various districts. In 1930, a beginning was made with the establishment of two stations: the Hilo Variety Station in the lower lands of Hilo Sugar Plantation Company, and the Kauai Variety Station in the middle belt of The Lihue Plantation Company, Ltd. In subsequent years, other stations were added. The Maui Variety Station, which was established in 1938 at Hawaiian & Commercial Sugar Company, Ltd., in an area selected as representative of a considerable portion of the Central Maui plain, was discontinued in 1953. The stations now participating in the cane breeding and testing project are listed in chronological order of establishment:

Station and Location	Elevation	Acres	Established
Waipio Substation (irrigated) Oahu Sugar Company, Ltd. (Reduced in 1949 to 47 acres)	50′	145	1911
Kailua Field Laboratory (semi-irrigated) Windward Oahu	75′	40	1926
Molokai Quarantine Station (irrigated) Mapulehu, East Molokai (Only cane quarantine area listed)	50′	4	1928) 1930)
Kauai Variety Station (semi-irrigated) The Lihue Plantation Co., Ltd.	350′	19	1930
Hilo Variety Station (unirrigated) Hilo Sugar Plantation Co.	500′	20	1930
Hamakua Mauka Variety Station (unirrigated) Hamakua Mill Company	1600′	14	1931
Kohala Variety Station (unirrigated) Kohala Sugar Company	900′	10	1932
Hamakua Makai Variety Station (unirrigated) Hamakua Mill Company	700′	15	1933
Ewa Variety Station (irrigated) Ewa Plantation Company	30′	10	1938
Helemano Variety Station (irrigated) Waialua Agricultural Co., Ltd.	650′	12	1938
Kau Variety Station (unirrigated) Hawaiian Agricultural Co.	2000′	13	1948
Waipio Mauka Variety Station (irrigated) Oahu Sugar Company, Ltd.	300′	27	1949

As indicated by the dissimilarities in elevation and in status in respect to irrigation, these stations vary widely in ecological conditions. They differ in the prevalence of certain diseases of sugar cane and in the extent to which sugar yield is affected by tasseling. Thus the regional station network provides a representative sample of many of the conditions under which sugar cane is grown in Hawaii.

SEEDLING TESTING ON THE PLANTATIONS

When the regional variety station network was first inaugurated, it was believed that the regional stations would be able to relieve the plantations of all

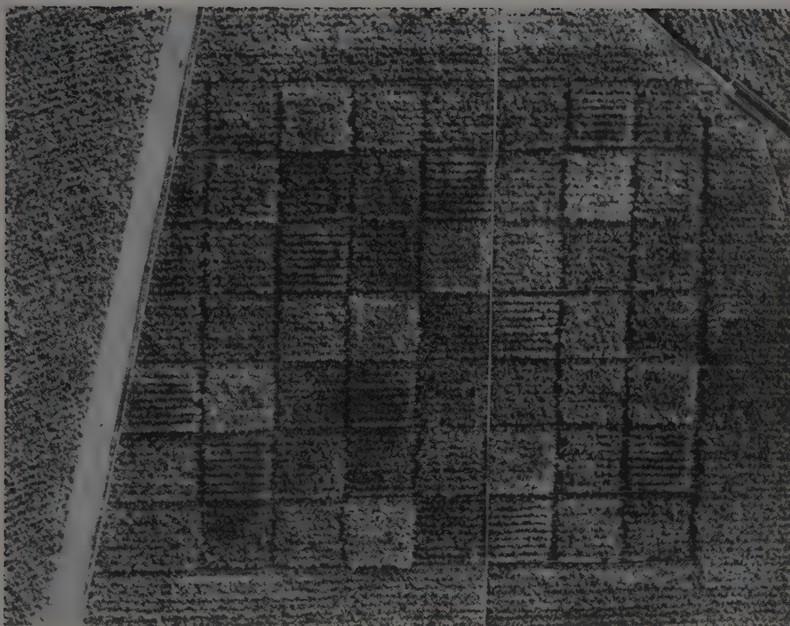


Figure 28. Aerial view of a replicated (final) variety test on an irrigated plantation.

except the final stage of variety testing. It soon became evident, however, that the limited volume of 30x30 testing that could be carried on by the regional stations was inadequate.

At the end of World War II, the aid of the plantations was solicited in this phase of testing. The response has been most gratifying. The volume of 30x30 testing now being handled by the plantations is such as to expedite materially the evaluation of the new canes released each year by the regional stations.

Under the present program, the sugar cane area of each plantation is to be demarcated into major ecological zones. Kohala Sugar Company, for example, has five such zones: (1) makai unirrigated, (2) makai irrigated, (3) middle belt —dry Hawi side, (4) middle belt—wetter Niulii side, and (5) mauka cold wet belt.

The program calls for one 10x15 planting each year in each such major zone. The chief function of the 10x15 planting is to produce seed for a 30x30 test to be installed the following year in the same zone. In addition, seedling performance in the 10x15 planting provides a basis for selecting the stronger candidates for 30x30 testing and for eliminating the poorer ones.

A typical plantation 10x15 planting occupies from ¼- to ½-acre and includes from 40 to 80 seedlings. The candidates are chosen on the basis of their performances both at the regional stations and at other plantations with similar environments.

From the 10x15 planting, the plantation selects the more promising candidates for 30x30 testing. A typical plantation 30x30 test occupies from ½- to 1½-acres

and includes from 10 to 30 seedlings, each seedling plot flanked by a check plot of the standard variety.

Performance in the 30x30 tests determines whether the candidate will be pitted against the standard variety in a final test, or whether it will be discarded.

FINAL TESTS—Only candidates which in 30x30 tests have shown evidence of being able to equal or outyield the standard variety are eligible for final testing. A typical final variety test contains from two to six varieties, including, of course, the standard variety of that locality. These tests are usually laid out in a randomized block design to permit the use of a variance analysis in determining the significance of the differences in yield. The minimum acceptable plot size has been set at one twenty-fifth of an acre. Where four or more varieties are being tested against a standard, it is recommended that two or more plots of the standard be included in each block (Figure 28).

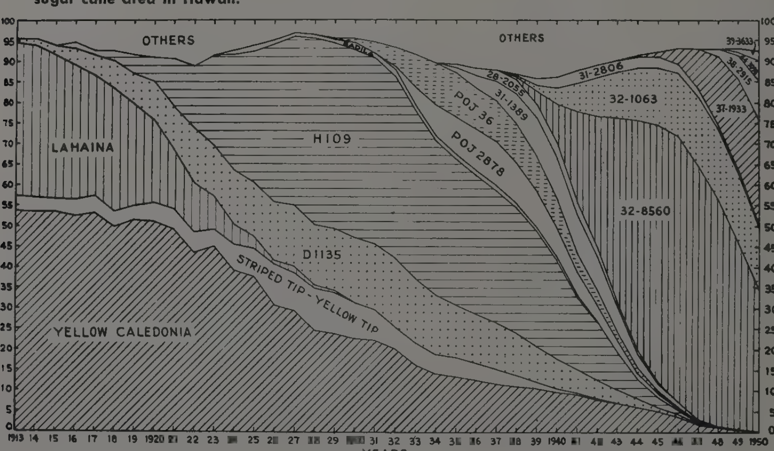
A factorial design, in which the candidates are tested under several contrasting levels of nitrogen fertilization, is favored for the final stages of final testing.

RECAPITULATION—The successive stages of testing and the time required by each are listed below:

Regional Stations		**Plantations**	
Field Nursery	— 1 year		
5 x 3	— 1 year		
5 x 6	— 1 year		
10 x 15	— 1 year	10 x 15	— 1 year
30x30 plant crop	— 18 to 24 mos.	30x30 plant crop	— 18 to 24 mos.
30x30 1st ratoons	— 18 to 24 mos.	30x30 1st ratoons	— 18 to 24 mos.
		Final Test — plant crop	— 18 to 24 mos.
		Final Test — 1st ratoons	— 18 to 24 mos.

The field nursery, 5x3, and 5x6 stages of testing are handled almost entirely by the regional stations; the final testing entirely by the plantations. The 10x15 and 30x30 stages are carried on in parallel by the regional stations and the plantations. As has been pointed out, experience has emphasized the necessity for joint participation in 30x30 testing if a bottleneck at this stage is to be forestalled.

Figure 29. Varietal changes from the years 1913-1950 expressed in terms of per cent of total sugar cane area in Hawaii.



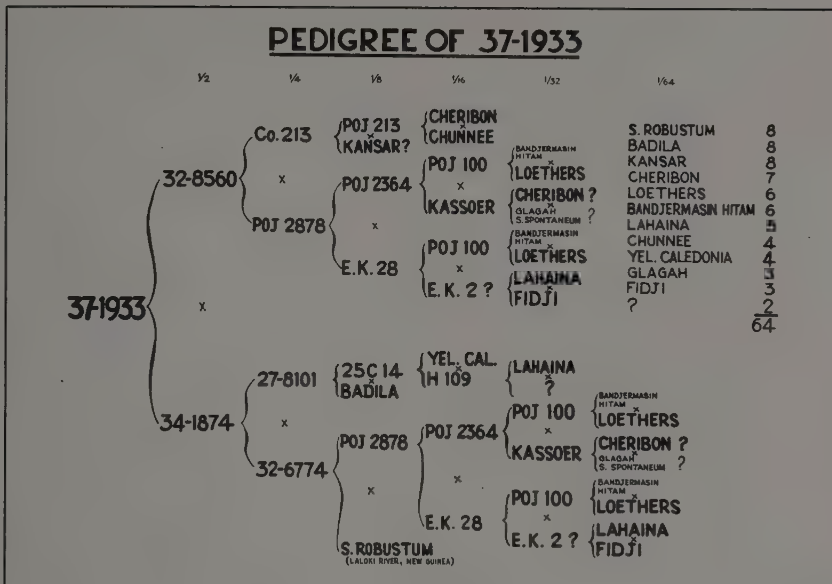


Figure 30. The pedigree of 37-1933, indicating the various sources of germ plasm and illustrating the diversity of blood lines in the ancestry of a modern variety.

Even without waiting for yield data from 30x30 ratoons, the testing program from germination to harvesting of the final test plant crop requires a minimum of nine years for completion. Thus the time interval from the germination of the new seedling to its adoption as a commercial variety for extensive field scale planting usually ranges from ten to fifteen years.

RESULTS OF THE BREEDING PROGRAM

Varietal Chart—1913–1951

The concrete results of sugar cane breeding are reflected in Figure 29 which shows the trends of the principal commercial varieties in Hawaii since 1913 when the first variety census was compiled. It may be of interest to examine the successive periods covered by this graph.

1913–1920—Lahaina declining rapidly. Yellow Caledonia declining slowly. D 1135 increasing slowly. H 109 beginning to expand.

1921–1930—Rapid expansion of H 109. Moderate expansion of D 1135 and the Tip canes. Extremely rapid decline of Lahaina, leading finally to complete replacement. Rapid decline of Yellow Caledonia.

1931–1940—Expansion of 28–2055, 31–1389, POJ 36 and POJ 2878. Decline of H 109, D 1135, Tip, and Yellow Caledonia. Beginning of rapid expansion of 32–8560 and 32–1063.

1941–1950—Decline and ultimate disappearance of 28–2055, 31–1389, POJ 36, POJ 2878, H 109, D 1135, Tip, and Yellow Caledonia. Rapid expansion and subsequent decline of 32–1063 and 32–8560. Expansion of 37–1933, 38–2915, 44–3098, and 39–3633.

THE FUTURE—The next decade will see the disappearance of 32–1063 and 32–8560, while 37–1933, 38–2915 and 44–3098 will continue to expand. It is probable also that new and as yet unrecognized varieties will enter the scene before the end of the present decade (Figure 30).

DEFICIENCIES IN THE BREEDING PROGRAM

In scanning the history of the past half century of sugar cane breeding, it is not difficult to see errors, both of omission and of commission, that must have tended to reduce the returns realized from the investment in the breeding program. A posteriori examination of these defects is pertinent only insofar as such an examination may help to point the way toward greater efficiency in the future. It is with this objective in view that we are now to examine the past record for shortcomings that might well be avoided in the future.

Limitations of the Breeding Collection

At each period in breeding history, the achievements attainable are delimited by the available parent material and by the effectiveness with which this parent material is utilized. We can see in looking back that much of the breeding effort during the first twenty-five years was foredoomed to disappointment because of the limitations of the parent material. Lahaina, Striped Mexican, Rose Bamboo, Tip, D 1135, and seedlings of these canes, were the parents most extensively employed. Apparently, the genes needed for the achievement of still higher yields were not represented in this small collection of noble parents. Uba had been available since the beginning of the century, but it was not utilized in breeding until 1923.

From the vantage point of the present, it is easy to see that if, as a first step in embarking upon its breeding program, the industry had undertaken the assembling of the most comprehensive collection of breeding material available, and if it had followed a program of exploring this breeding collection in as wide a diversity of combinations as possible, the chances of success would have been greatly augmented.

In looking toward the future, we see that the present breeding collection is still far from complete. Extensive regions remain to be explored for useful sugar cane germ plasm. The chances of success in the future, as in the past, will be limited by the breeding material at hand, and by the effectiveness with which this material is utilized in further synthesis. We must continue to take advantage of every opportunity to strengthen the breeding collection.

Exchange of breeding material among the various stations engaged in sugar cane breeding has contributed heavily to the progress achieved during recent years, as evidenced by the pedigrees of the leading varieties of Hawaii and of other regions. It is to be hoped that the advantages to be realized from a free exchange of breeding material will be more fully exploited in the future.

Inter-Generation Interval Excessive

A review of the history of breeding, not only in Hawaii but throughout the sugar cane world, shows that the interval between successive generations has often been unduly long. In our most recent populations of seedlings, the inter-generation interval averages nine years. Earlier populations show an even longer

average interval. On the basis of the present average, some 27 years would be required to synthesize a variety in which are combined the desired traits of eight great-grandparents.

Much of the sugar cane breeding of the past, not only in Hawaii but also in other countries, has consisted of a search for "nicking" combinations: crosses that produce higher than average proportions of selectable seedlings. Once such a superior combination has been identified, the cross has then been repeated on a large scale, sometimes year after year, in order to exploit its possibilities to the fullest.

A basically different line of attack is one that emphasizes the utilization in further crossing of the superior new seedlings themselves, rather than the large-scale repetition of the crosses that produced those superior seedlings.

Theoretical considerations, as well as breeding experience during recent years, indicate that more rapid progress is to be made by following the second alternative. Recurrent, generation-by-generation selection provides a powerful lever for shifting gene frequencies in the desired direction. Moreover, the synthesis of a superior individual endowed with the desirable traits of a large number of parent lines can be achieved only through generation-by-generation progression. The combining of the desirable traits of two parents can sometimes, with good luck, be accomplished in a single generation. The combining of the desirable traits of four grandparents requires a minimum of two generations, of eight great-grandparents, three generations, and so on. It is evident that the rate of progress will be determined to a considerable degree by the number of generations that can be realized within a specified period of years.

It is true that in particular instances the interval between generations has been shorter than the present nine-year average for Hawaii. Often, however, it has been much longer. Although sugar cane breeding in the modern sense has been under way for more than sixty years, there are few, if any, commercial varieties in the world that represent more than six generations of breeding. Sugar cane breeding is truly in its infancy; a good beginning has been made, but hardly more than a beginning.

Need for Further Improvement in Breeding Techniques

The most important contribution to sugar cane breeding technique in Hawaii since its beginning in 1905 has been the development of the SO_2 method. However, there is still room for improvement, since even with the addition of phosphoric acid, some varieties still fail to live satisfactorily in the solution. Further experimentation aimed at improving the solution should be carried on as opportunity permits.

Equally important benefits to sugar cane breeding would accrue from the development of a means of inducing tasseling at will. Such a development would provide the breeder with the tassels of the light-tasseling varieties which he needs in breeding toward freedom from tasseling. It would enable him to synchronize the tasseling of the early and late tasselers, thus achieving combinations that he is at present unable to make. Finally, it would enable him to extend the crossing season beyond the period of normal tasseling. In Hawaii, the briefness of the tasseling season imposes a serious bottleneck upon sugar cane breeding.

While perhaps less important than a positive means of inducing tasseling, an economical means of preventing tasseling on a field scale would also be helpful to the breeder. Many seedlings that are otherwise superior must at present be discarded because of excessive tasseling. An economical means of preventing tasseling would enable such seedlings to qualify as commercial varieties. All too frequently, the rare light-tasselers or non-tasselers, even in the best populations, are deficient in other respects.

Further studies aimed at developing economical procedures both for induction and for prevention of tasseling are urgently needed. Until such means can be perfected, it will be necessary to maintain, in the breeding plots, large plantings of the reluctant tasselers in order to provide even a few tassels of this category for use in breeding.

More Rigorous Selection Needed

It has long been apparent that, even in the best populations, the proportion of commercially useful seedlings is extremely low. However, we have been backward in revising our selection procedures to conform with this fact. In looking back, we can see that greater returns could have been realized from the breeding investment under a more daring and more rigorous selection policy. The program has too long been dominated by the fear that a superior seedling may escape recognition. This fear has led to the testing and retesting of all seedlings that appeared to have even a remote chance of qualifying as a commercial variety.

The effort expended upon second-choice material has failed to uncover even a single variety of commercial stature. Meanwhile this diversion of effort has precluded the germination and testing of additional thousands of combinations and millions of seedlings that might have been explored under a program of more rigorous selection. We need to face the fact that the losses inflicted by failure to explore larger numbers of promising combinations are just as real as, and potentially much greater than, those that could result from failure to recognize a superior individual among the populations grown.

While considerable progress has been made, there is opportunity for further improvement in the direction of streamlining procedures to permit the stretching of available funds to cover the testing of larger populations of seedlings derived from a greater diversity of combinations. In working toward this objective, more rigorous selection is of the essence.

Localized Testing Indispensable

The establishment in 1911 of the 110-acre Waipio Substation provided ample area for the testing of new seedlings. For nearly a decade, however, Waipio was the sole regional station. Here it was necessary to carry on the preliminary selection of seedlings for districts that differed greatly in soil and climatic conditions not only from Waipio but from each other.

With the development of the Manoa Substation in the early 1920's, land became available for the preliminary testing of seedlings under rainy upland conditions. Unfortunately, the Manoa lands were virgin lands; in this and in certain other respects, they were not representative of the lands on which the selected seedlings would have to compete.

In 1926, the Kailua Substation was established on the abandoned rice paddies of stream bottom lands. These lands, too, were virgin to sugar cane. As to soil type, they differed radically from the cane lands of the Territory, except perhaps for a small area at Kahuku. In later years, the bottom lands were abandoned; they were replaced with an upland area similar in soil type to the middle belt lands of windward Kauai.

There can be no doubt that the efficiency of breeding and testing in those early years was adversely affected by the discrepancies between the environmental conditions of the testing stations and those of the plantation fields.

It was not until the ten regional stations were established, in 1930 and thereafter, that areas representative of the major sugar cane regions of the Territory became available for large-scale preliminary testing of new seedlings.

Experience has shown that it is inefficient to carry out selection under conditions quite different from those under which the seedlings must eventually compete. We know of no satisfactory substitute for testing under the precise conditions that must be met in actual practice.

Improvements for Greater Efficiency in Testing

Improvement in efficiency of testing has resulted from adoption by regional stations and plantations of a uniform system of preliminary testing, from standardization of terminology and from systematizing of records (field ledgers and Master File).

There is need for further improvement, particularly in the following respects:

1. With the disappearance of experienced cane cutters and with rising labor costs, the problem of harvesting 30x30 and Grade A variety tests becomes increasingly acute. More efficient and less costly procedures are urgently needed. Prospects for the development of effective mechanical cutting appear to be good. It has been pointed out that if a four-line strip could be cut mechanically from the middle of an eight-line plot, the TC/A yields could be calculated on the basis of the tonnage of cane cut and of the actual area of the swath from which this cane was removed.

2. With the installation at the mill of cane cleaners ahead of the crushers, the problem of obtaining reliable juice samples has been aggravated. It is to be hoped that the time will come when every mill will be provided with facilities for by-passing the cleaning plant so that clean cane from experiments can be fed directly into the crusher. Wherever it is impossible to obtain reliable crusher juice samples from experimental cane, the situation must be regarded as unsatisfactory. Inability to obtain reliable sucrose determinations on sample cane constitutes a serious weakness and one that is likely to prove costly in the long run. An industry that is unable to determine accurately its field-by-field and variety-by-variety sugar yields is hardly justified in referring to its agriculture as scientific.

3. There is need for further improvement in the precision of field trials. First class, careful work costs but little more than slipshod, careless work. The former can provide valuable guidance; the latter is likely to produce misleading results. Erroneous figures from variety tests may lead to the discarding of a valuable seedling or to the retaining of inferior seedlings for further testing. Fluke results are expensive; they entail an undue amount of subsequent testing to get at the facts.

Any development that can lead to greater economy or to greater accuracy in variety testing will indeed be a contribution to the economic well-being of the industry.

AIDS TO VARIETAL RESPONSE

Forestalling Yield Decline

Of late years, little attention has been given to seed selection. In spreading new varieties, seed is usually cut from whatever sources happen to be conveniently available, taking the stalks as they come, the weak with the strong.

It is possible that the life expectancy of a new variety might be lengthened if, in the course of spreading, care were taken to select only healthy stalks from vigorous stools and to reject those that are below par. Hot-water treatment of seed destined for planting in seed nurseries may also help to control some of the known, and possibly also, some of the still unidentified systemic diseases. The incorporation of a suitable insecticide in the hot-water bath to eliminate mealy bugs and thus to delay the establishment of this pest in plant fields, may prove advantageous.

Adequate seed bed preparation to eliminate volunteer stools may help to reduce the carry-over of pathogens from the preceding to the subsequent crop. Moreover, complete elimination of volunteers before planting the seed nursery is desirable from the standpoint of obviating mixtures or rogues that would otherwise develop from the stubble.

Good Farming Essential for Good Varieties

In Hawaii, as in other regions, there has sometimes been a tendency to rely upon more vigorous varieties to compensate for unsound farming practices. The futility of such a course has become abundantly evident. The best variety in existence can be reduced to mediocrity by restricting any one of the many growth factors with which it must be provided in order to produce high yields.

The replacement of an old variety by a new and potentially higher yielding variety calls for a re-examination of cultural practices. It is hardly to be expected that the cultural requirements of the new variety will be identical in all respects to those of the variety which it has displaced. Better varieties and better farming must go hand in hand if maximum yields are to be realized.

CONCLUSION

Since 1905, the industry has invested many millions of dollars in its breeding and testing program. The favorable effects of improved cultural practices combined with the higher yielding ability of the new varieties have resulted in a gradual increase in per acre yield. Such an increase is remarkable in view of the cumulative effects of unfavorable factors usually encountered when a single crop is permitted to occupy the land continuously without benefit of rotation or fallow. It is all the more remarkable in view of the sugar losses entailed by rake and grab harvesting and by present cleaning procedures.

It is altogether likely that the maintenance of high yields under a one-crop system of agriculture will in the future depend increasingly upon breeding as a means of outmaneuvering the pathogen complex which, under continued cropping

with a single variety, may be expected to exact an increasingly heavy toll from successive crops. In any event, every effort must be made to maintain the breeding program at the highest possible level of efficiency if maximum returns are to be realized from this heavy annual investment.

Optimism as to the prospects for future progress in sugar cane breeding in Hawaii finds support in the following considerations:

The breeding collection has been strengthened by importations of new blood lines and by the synthesis of breeding canes that combine light tasseling with second-season growing power and tolerance for poor soils. A good beginning has been made, but much remains to be done. The potentialities of the world's resources of sugar cane germ plasm have scarcely been tapped.

More efficient crossing and testing procedures have been developed and further improvements may be expected.

- The sulphurous-phosphoric acid crossing technique facilitates both biparental and melting pot crossing.
- Increasing use is being made of melting pot crossing for special conditions, e.g., the mauka melting pot, the makai leeward melting pot, the makai windward melting pot, and others.
- Greenhouse facilities have been augmented.
- Propagation procedures have been improved. Individual potting has been replaced by bunch planting.
- Establishment of the regional station network has provided for localization of testing.
- Plantations and regional stations have adopted a uniform testing procedure.
- Recording of notes and maintenance of records have been systematized, e.g., field ledgers and Master File.
- The participation of the plantations in the seedling testing program has become more extensive and more effective.

The annual investment by the industry in sugar cane breeding is approximately equal to the loss that would be entailed by a yield decline of one-half of one per cent. There is reason to believe that if the industry were obliged to carry on indefinitely with its present varieties, the decline in yield would eventually, and perhaps soon, exceed by a wide margin the break-even point of one-half of one per cent.

A strong breeding program will provide a continuing replacement pool to be drawn upon if and when a standard variety should begin to fail. An active seedling testing program on each plantation will help to insure detection of yield decline on the part of any one of the standard varieties before its effect has reached serious proportions.

THE EVOLUTION OF A PHILOSOPHY ON SUGAR CANE BREEDING IN HAWAII

John N. Warner[1]

INTRODUCTION

Maximum returns per dollar expended is the major objective of the sugar cane breeding program conducted by the Experiment Station of the Hawaiian Sugar Planters' Association. In striving to meet this objective, this Station has evolved, over the past thirty years, a philosophy and a number of techniques, some of which have been adopted by sugar cane breeders in other parts of the world, while others are subject to professional differences of opinion, perhaps because they are little understood. It is the object of this discussion to clarify some of the controversial points and to elaborate on the evolution of the philosophy which forms the present basis of the Hawaiian breeding program.

The general objective of the breeding program is to produce improved varieties of sugar cane which yield more tons of sugar per acre-month, which are resistant to diseases and pests, which are free from disqualifying factory characteristics, and which are better suited to the environment and agronomic practices under which they are grown. Over the years an "Hawaiian type" of sugar cane, particularly adapted to sugar cane agriculture in Hawaii, has been evolved. Because sugar cane crops in Hawaii are grown for approximately two years before harvesting, it is important that the natural tendency toward annual growth and flowering be minimized in any successful variety. The ideal Hawaiian type would be a non-flowering cane which lodges without damage and which does not suffer too severe a reduction in rate of growth during the cooler winter months and during the second year of the two-year crop. The variety should also have the ability to produce and maintain heavy tonnages over the entire crop cycle without deterioration. These characteristics, "unnatural" as they are to the sugar cane plant, are all-important in Hawaii, and should be kept in mind as factors which reduce the proportion of individuals able to qualify as commercial varieties in Hawaii. Synthesizing a variety which combines these "unnatural" characters with all of the other traits essential to high yield presents a problem which may be attacked by propagating seedlings in small numbers each year over a period of many years.

[1] The author, Senior Geneticist, Experiment Station, HSPA, wishes to acknowledge the invaluable assistance of Dr. A. J. Mangelsdorf, Principal Geneticist, and of all other members of the Genetics Department for their part in the preparation of this manuscript.

It may also be attacked by growing larger populations each year from a greater diversity of combinations with the object of reducing the number of years required to attain the desired goal. The breeding program in Hawaii leans toward the latter alternative.

While most of the techniques employed in breeding sugar cane in Hawaii have been discussed in various publications[2], it seems appropriate to review briefly the present status of the program. The main features of the breeding program of this Station may be enumerated as follows:

1. ASSEMBLING AND MAINTENANCE OF A BREEDING COLLECTION. The sugar cane breeder is unable from a practical standpoint to create new and useful genes. To provide the building material which he must have in order to synthesize superior new varieties, he must assemble and maintain as comprehensive a collection of breeding material as his budget will afford. The Station's breeding collection is maintained at the Kailua Field Laboratory, in an environment particularly conducive to heavy tasseling of sugar cane.

In the following classification of the more important sources of breeding canes, the approximate number of varieties of each category in the collection maintained by this Station is shown in parentheses:

(a) Representative clons of the wild and primitive species of the genus *Saccharum* and of closely related genera (111).

(b) Varieties of noble canes, *S. officinarum*, and representative clons of breeding and commercial canes bred in other countries (192).

(c) Hawaiian-bred seedlings, including commercial canes and canes selected for breeding purposes; e.g., hybrids and quarter-breeds of canes in Class (a) and Class (b) (approximately 1350).

2. CHOICE OF PARENTS. In order to create new gene combinations which may contain outstanding individuals, the breeder must first choose the parents. The choice of parents is a difficult and a somewhat controversial matter which will be discussed more fully in a later section. In Hawaii, parents for commercial crosses are chosen either on the basis of their own characteristics and capabilities or because they have produced, in trial crosses, better than average populations of seedlings. It is reasonable to assume that, considering the rarity of elite clons of sugar cane in relation to the size of the populations from which they were selected, such clons represent exceptional combinations of desirable genes. The employment of successive generations of these exceptional combinations, a technique known as recurrent selection, is an essential feature of the Hawaiian sugar cane breeding philosophy. Not only is the complex of genes leading to the Hawaiian type of sugar cane eventually brought in from both sides of the cross, thus raising the average goodness of the progeny, but by using genetically diverse parents, ample genetic variation in progenies, a prime requisite for effective selection, is provided.

3. CROSSING TECHNIQUES. The actual crossing work is largely carried out by means of the sulphurous acid-phosphoric acid solution technique, developed by this Station to maintain the cut tassels during crossing and ripening of seed. The

[2] See the Annual Reports of the Experiment Station Committee, HSPA, (included in the Printed Reports of the Annual Meetings of the HSPA); Proceedings of the International Society of Sugar Cane Technologists; Hawaiian Planters' Record; Proceedings of the Jamaica Sugar Technologists Assn. 1950; Reports of the Hawaiian Sugar Technologists; Journal of Economic Botany (April-June 1950); and others.

flowering stalks that are to be used in crossing are cut, with four to five feet of stalk, when the tip of the panicle has begun to bloom. From this time on until pollen-shedding of males or seed-ripening of females is completed, the cut ends are kept in the acid solution. In this manner the tassels may be kept alive for approximately three weeks.

Various types of crosses are made each year, both for production of seedlings for commercial testing, and for development of breeding canes. The crosses made during the 1951–52 season were as follows:

General melting pot crosses 1495

The general melting pot provides a means of evaluating varieties as female parents and of effecting a wide diversity of combinations among selected breeding material. Only the female parent is known.

"Mauka" melting pot crosses 170

Similar to the above, except that the parent varieties are selected on the basis of their suitability as breeding canes for "mauka" areas, which lie at high elevations, have poor soils, cool temperatures, and cloudy weather.

Super melting pot crosses 362

Similar to the above, except that males are admitted only if known to produce superior offspring or if endowed with exceptionally desirable qualities.

Wild melting pot crosses 51

This melting pot provides an opportunity for *spontaneum* and *robustum* hybrids or quarter-breeds to cross *inter se* with the object of producing superior breeding canes.

Bi-parental crosses 689

Each cross involves two selected parents. The cross is carried out under isolation, so that both parents are known.

Selfiings 18

Certain varieties are selfed in an effort to produce seedlings of breeding value or to determine their degree of self-fertility.

Field crosses collected 236

Tassels are collected in the field after blooming is completed. If only a single male variety is present in the vicinity, both parents are known—otherwise only the female parent can be known with certainty.

Total 3021

4. SEEDLING PROPAGATION. Fuzz, the mature seed, is planted in flats of sterilized soil in a large greenhouse on the Station grounds in Honolulu. The flats of germinated seedlings are handled in one of three ways and the number of flats handled in each manner in 1951 is shown in parentheses:

(a) Bunch plantings: Seedlings in flats having light to average germination are transplanted in bunches of 5 to 15 seedlings each from the original flats directly into the field (2641 flats).

(b) Bunch transplanting: Seedlings in flats which have germinated more heavily, or flats in which a higher survival is desired, are "bunch transplanted" in the greenhouse at an age of about three weeks, one flat being so transplanted into two to five flats of 30 bunches of 5 to 10 seedlings each. (1665 bunch transplanted flats set out in the field.)

(c) Individual transplantings: In certain crosses, survival of every seedling is desired. Seedlings from such crosses are individually transplanted into new sterile flats, 48 per flat, at about three weeks of age. When transplanted into the field, the individual seedlings are spaced in the row to insure maximum survival and a more adequate basis for evaluation at time of selection (85 individually transplanted flats set out into the field).

5. SEEDLING SELECTION AND EARLY TESTING. The seedlings in the first four stages of testing, (field nursery, 5x3, 5x6 and 10x15) undergo selection at the end of a 12-month plant crop. Facilities for early testing of a large number of seedlings over the wide range of environmental conditions in Hawaii are afforded by the Kailua Field Laboratory (breeding station) and a network of eleven variety stations. Those seedlings which, on the basis of their performance in preliminary trials, appear to have commercial possibilities are distributed to the plantations.

Plantation testing begins with the 10x15 stage. A typical plantation receives 50 or more new seedlings per year for 10x15 testing in each of its environmental zones. From these the plantation will select for 30x30 testing those seedlings which appear most promising under the specific conditions to be met.

Selection at each level of early testing is based on many considerations, the more important being:

(a) general vigor, adequate stooling, drought resistance, and suitability to the particular area
(b) agronomic characteristics and growth habit suitable to Hawaiian practices
(c) sucrose content
(d) resistance to diseases and insect pests
(e) freedom from tasseling and other inherent disqualifying features
(f) past and current record of the seedlings at the same and at different locations

6. PRELIMINARY YIELD TRIALS (30x30). Seedlings selected from the 10x15 stage at the variety stations or on the plantations are advanced to the 30x30 stage of testing. Here a new seedling is first tested for yield in both plant and first ratoon crops on a two-year cropping cycle. Since individual seedlings are usually unreplicated in a single test, this stage is strictly a preliminary yield trial. Replication is achieved by including in further 30x30 tests those seedlings which continue to show promise.

7. FINAL TESTING. In cooperation with the plantations, replicated final yield trials are installed in appropriate environments. In these final trials, the best of the new seedlings which have shown promise in preliminary yield trials are tested against the standard varieties.

8. MASTER FILE. Performance data on each seedling under active test are recorded in a central file known as the Master File. The Master File provides a complete performance record of each seedling that has received its permanent number. A new seedling receives its permanent number when it is advanced from the 5x3 to the 5x6 stage of testing. The record covers not only the various regional station plantings, but also each plantation planting in which the seedling appears.

A comparison of the current breeding program at the Experiment Station, HSPA, with sugar cane breeding programs in other parts of the world brings to

light several noticeable differences. Four conspicuous features of the Hawaiian program are, first, the means which have been devised to produce a large number of combinations economically, e.g. melting pot technique; second, the procedures whereby a large number of seedlings can be handled economically in the field nurseries, e.g. the bunch planting; third, the decentralization of preliminary testing by means of the regional station network; and fourth, centralization of records of performance at the regional stations and on the plantations.

In general, sugar cane breeding programs in other countries are based entirely on bi-parental crossing and initial handling of seedlings as space planted individuals, the preliminary testing usually being carried out at a single location until the new varieties are candidates for replicated field testing.

It may be of interest to consider the reasons for our deviations from the more conventional cane breeding procedures. It is hoped that the discussion which follows will help to clarify the issues.

THE OBJECTIVE

The objective of breeding in Hawaii, reduced to its simplest terms, is to produce for each environmental condition canes which give maximum yield of sugar per acre-month at minimum cost. To a plant breeder, this means the producing of new combinations of genes which interact with their environment, including the agronomic system under which they are grown, in such a way as to give increased yields.

As the plant breeder breaks down his task into its component parts, he encounters first of all the problem of producing new combinations of genes. There are several ways in which this can be done. One way might be to wait for naturally occurring mutations to appear. However, in sugar cane, because of its heteroploid nature[3], fortuitous mutations, most of which are recessive and deleterious, do not appear to offer a fruitful means of advancement. Rate of mutation may be increased by treatment with X-ray or other mutagenic agents, but the amount of profitable variation created would be small and random in effect. It is the consensus among plant breeders that the creation of genetic variability through sexual reproduction affords infinitely greater likelihood of success, providing that the choice of parents is an intelligent one, and that effective selection among the progeny can be exercised. In the last analysis, plant breeding as a science is nothing more than accelerated and directed evolution. Evidence from many sources indicates that the opportunities for segregation and recombination afforded by sexual reproduction are indispensable to rapid evolutionary progress.

SUGAR CANE AS A SUBJECT FOR BREEDING

Before considering some of the complexities of sugar cane breeding, it may be desirable to consider the plant with which we are working.

Members of the genus *Saccharum*, including sugar cane and its wild relatives, behave genetically like other plants. We have no reason to believe that sugar cane is in any way unique in respect to the fundamental principles of genetics, established, as they have been, from the study of insects and other animals, and

[3] Present day commercial varieties of sugar cane usually have a chromosome complement which can be represented by the formula $a\ n + x$, where a is a factor of polyploidy in the range 8 to 12, n is the basic number of chromosomes, thought to be 10, and x the minor variation which precludes the classification of sugar cane as a simple polyploid. x may vary from 0 to 9.

of fungi and higher plants. It follows, therefore, that any approach to the breeding of sugar cane must be formulated on an adequate understanding of basic genetic principles.

The original native chewing canes as well as most of the original commercially cultivated varieties, generally called noble varieties, belong to the species *Saccharum officinarum*. This species, while capable of sexual reproduction, has for many centuries been propagated primarily by cuttings. The "original" noble varieties are believed to be the product of selection by primitive peoples exercised upon genetically variable populations of chance seedlings resulting from crossing, first in wild populations and later in native gardens. In general, these old noble varieties are soft, juicy, low in fiber, and relatively sweet. Most of them, because of disease susceptibility and lack of vigor, are no longer suitable for commercial planting. It is doubtful if any of them would long persist in the wild; they owe their survival to care and protection by man.

There are also two primitive cultivated species of *Saccharum*, *S. barberi* and *S. sinsense*, not so soft or sweet as the noble canes, but nevertheless not so hardy as the two wild species of the genus, *S. spontaneum* and *S. robustum*. Both of these wild species are able to survive in nature without the aid of man. They encompass a wide range of diverse forms all of which are hardy, low in sucrose and high in fiber.

All members of the genus *Saccharum* are heteroploids; most are basically hexaploid or higher. Cross fertility is the rule even in crosses between parents which differ markedly in chromosome number. Fertility in inter-specific crosses within this genus is common. All of the commercial canes now grown in Hawaii have resulted from the hybridization of two or more species.

Sugar cane is naturally highly heterozygous; that is to say, it does not breed true from seed. This condition is expected as the result of cross fertilization (its pollen is carried by the wind) and is similar to that found in other cross-pollinated organisms. While each species of *Saccharum* breeds reasonably true for those traits which characterize the species, individual clons within the species show considerable variation. Progeny of crosses between such clons within a species fall within the limits of the species but differ among themselves. As with dogs, for example, mating two pure-bred spaniels results in a litter of pups differing among themselves but nevertheless adhering closely to parental type. Even a cross of a Dachshund and a Collie results in dogs, but subsequent generations of the progeny will show considerable variation.

In comparison with the other major crops, sugar cane offers both advantages and disadvantages to the breeder. On the credit side is the ease with which sugar cane may be propagated asexually, thus permitting rapid exploitation of any particular outstanding genotype. It is not necessary, as in corn, to produce and maintain inbred lines in order to perpetuate a given genotype. The ease with which crosses can be made by means of the sulphurous acid technique is also a great advantage, since in the absence of this technique crossing is laborious and time-consuming.

On the debit side are: the relatively short flowering season in Hawaii; the difficulty in preventing pollen and seed contamination, both pollen and seed being readily transported by wind; and preclusion of manual emasculation because of the small size of the individual flowers. Another disadvantage is the difficulty of

making certain desired crosses due to discrepancies in the flowering periods of the proposed parents, to the failure of one or both parents to produce tassels in sufficient number, or to the presence of pollen sterility in both parents.

Male sterility is common—it is often associated with fair to good female fertility. Among the male-fertile individuals, partial or complete self-sterility is the rule rather than the exception, although full self-fertility is occasionally encountered. Selfiing, as a breeding procedure, will be discussed fully in a later section. As female parents, male-sterile varieties offer the advantage of certainty that all of the offspring will have resulted from crossing. However, male-sterile varieties suffer a disadvantage in that they can be crossed only with male-fertile varieties.

Because emasculation is impractical, male-fertile varieties, which are at the same time self-fertile, are likely, if employed as female parents, to produce populations which contain, in addition to the desired cross, an unknown proportion of seedlings which have resulted from self-fertilization. Such "selfs" are generally deficient in vigor and are not likely to be selected for further testing in populations containing a high proportion of seedlings resulting from crossing. It may be assumed with a fair degree of certainty that vigorous individuals selected from among such mixed populations have resulted from crossing rather than from selfing.

As in the breeding of other crops, sugar cane breeding is a process of producing new combinations of genes and selecting, from among the great preponderance of mediocre combinations, those few that result in improved plants. The effects of certain genes may be expressed in clear-cut, visible characters. Characters with this type of expression, where the segregating individuals can be classified into clearly defined groups, are known as qualitative characters. Examples found in other crops are numerous and include albinos vs. normals, purple vs. green corn, many kinds of disease resistance vs. susceptibility, etc.

Characters which exhibit continuous variation, making separation into distinct classes difficult, and which usually must be measured in order to be recognized, are known as quantitative characters. Almost all of the characters of economic importance in sugar cane belong to this latter category. Yield, for example, which in the ultimate analysis is the main object of our program as it is in most other plant breeding programs, is a quantitative character, and a highly complex one. Specifically, our objective is maximum yield of sugar per acre-month so combined with minimum production, harvesting, and processing costs, as to produce maximum net returns per acre-year. Other examples of characters which behave in a quantitative manner are juice quality, stalk diameter, tasseling, etc.

Yield is the resultant of a number of component interacting quantitative characters, each of which plays its part in determining the outcome. The more important of these are: vigor expressed in number, diameter and length of stalks; sucrose content; ability to withstand deterioration; resistance to disease and insect attack; freedom from tasseling and other defects; adaptability to agronomic practices; and suitability for milling procedures. The interactions among these characters are exceedingly complex. It is not enough to produce sugar at a high rate in the field if, as a result of deterioration before harvest, it cannot be recovered in the factory. There is a natural reluctance to adopt varieties which are below par in respect to juice quality, but if the yield of sugar per acre-month can be improved by so doing, the increased yield may more than pay for the addi-

tional harvesting and milling costs. In situations where weed control is not a serious problem, an "open" type of cane may, because of higher yields and in spite of mediocre weed controlling ability, prove more profitable than the dense, closing in types. On the other hand, where weed control is a major cost item, it may be cheaper to grow a cane with good inherent weed controlling ability, even at some sacrifice in yield. Canes which give an early dense cover tend to have a low production ceiling under long cropping, due to their disposition towards "self-composting" and deterioration in the second season. In general, vigor is positively correlated with ability to control weeds, suitability for rake or grab harvesting, ability to ratoon, and ability to prevent soil erosion. Vigor tends to be negatively correlated with freedom from tasseling and with high sucrose percentage, but a certain minimum of vegetative vigor is indispensable to the success of any commercial variety, and canes combining good vigor with high sucrose or freedom from tasseling, or both, do occur as rare segregants. Under two-year cropping, high sucrose content may not assure high recoverable sugar in a variety subject to deterioration. As suggested above, the complexities of interacting factors affecting yield are many. Only a few of the more obvious have been mentioned.

THE INTRODUCTION OF PARENTAL MATERIAL

One of the most important phases of the breeding program is the assembling of parents from other parts of the world for crossing and back-crossing to the better class of Hawaiian breeding material in order to incorporate new genes and gene combinations into the program. These introduced varieties fall into three categories: outstanding commercial canes; breeding canes; and wild relatives of sugar cane. During the past 25 years, the breeding collection has benefited from participation by members of the Station staff in a number of expeditions in search of new sugar cane germ plasm[4]. Canes of all three of the above categories have been imported as a result of these expeditions. Visits and correspondence with sugar cane breeders in other countries have also led to a fruitful exchange of breeding material.

It has not been possible thus far to utilize some of the wild canes which tassel too early to permit crossing with the later-flowering noble types. Efforts to synchronize the flowering seasons through day-length control, trimming of leaves, chemical sprays, etc., constitute a continuing project.

Although much exploration and collecting have been done, there are still many areas that have not been thoroughly sampled for breeding material where sugar cane and its wild relatives are indigenous or have been cultivated since antiquity. Most of New Guinea, especially Dutch New Guinea, Indonesia, Borneo, Celebes, Burma, Thailand, Indo-China, and Malaya, have not yet been thoroughly cov-

[4] 1928–29 C. E. Pemberton to New Guinea with the USDA Expedition.
1929 A. J. Mangelsdorf to Java, Philippine Islands, Formosa, Burma, India.
1930 U. K. Das to India.
1930 C. G. Lennox to Australia.
1930–31 H. L. Lyon to India, Sumatra, Java.
1937 C. E. Pemberton and C. G. Lennox to New Guinea, New Britain, New Ireland, and vicinity.
1940 A. J. Mangelsdorf to Canal Point, Florida; Puerto Rico; British West Indies; Louisiana.
1946–47 A. J. Mangelsdorf to Formosa, Guam, and Saipan with the USDA Expedition.
1947 R. Urata to Canal Point, Florida; Summit, Canal Zone; Louisiana.
1950 A. J. Mangelsdorf to Canal Point, Florida; Cuba; Jamaica; Louisiana.
1951 J. N. Warner to Fiji; New Guinea; Australia.

ered. Continued study and collection of members of the genus *Saccharum* in these areas constitute one of the most important and potentially remunerative fields of basic research for the sugar cane breeder. In addition, the breeding program benefits from continued importation of new breeding material in the form of commercial varieties and breeding canes from other countries where sugar cane breeding is being actively carried out.

CHOICE OF PARENTS

The considerations that determine the choice of parents constitute another area of importance in the philosophy of the breeding program of this Station. In this connection two points may be mentioned: first, the importance of continual introduction of new germ plasm in the form of wild relatives of sugar cane, pure noble types, and hybrids; and second, the utilization of this material in combinations with the best representatives of the Hawaiian type. It is only through such means that genetic variation can be increased in our populations to make possible even more extreme and more desirable genotypes.

The development of the "Hawaiian type", a class of canes endowed with a high proportion of the genes essential to success under our environmental conditions and agricultural practices, has been a gradual evolutionary process. The fact that progenies from crosses among members of the Hawaiian group are generally superior to crosses involving a foreign cane as one parent, is in itself evidence that the breeding program has made important progress. This improvement in adaptation and type can be attributed to the effectiveness of a planned program of recurrent selection. Instead of going back to parents that have produced elite progeny, it has proved more efficient to use those rare elites themselves in the next generation of breeding. Repeating on a larger scale a cross which yielded an outstanding variety has been tried extensively on many occasions, but this procedure has rarely resulted in the discovery of another variety equally good or better than the one initially selected. On the other hand, a study of selection rates, based upon the ratio of the number of original seedlings reaching maturity to the number in the select list of canes under test, indicates that the recurrent selection approach offers considerable promise. Based on 1952 studies, the selection rate among seedlings of POJ 2878, considered a good breeder in many sugar cane areas, is one in 54,141. For 32–8560, an outstanding POJ 2878 hybrid, the ratio is one in 10,859. An outstanding 32–8560 hybrid, 37–1933, has a ratio of one out of 3886. Another 32–8560 hybrid, 39–7028, whose utilization as a parent is limited by its non-tasseling tendency, shows a ratio in the select list of one out of 180. All but one of the 32–8560 seedlings which appear as parents of canes on the select list have better ratios than 32–8560. This is strong evidence for the superiority of breeding with successive generations of elite hybrids over repeating the crosses between the original parents. The fact remains that it may be unwise to discard the parent material too hastily. Such material may contain genes that are of no importance under present conditions, but that may become important in the future. Examples of this category are genes for resistance to diseases that have not yet become established in Hawaii.

The "melting pot", to be discussed more fully in a later section, was first devised to evaluate the breeding value of a number of parents. The appraisal may be made either on the basis of the general appearance of the seedling populations

or of a study of the frequency of the progeny in the "select list". Both procedures are being used at the present time.

Studies of the parentages of the seedlings in the "select list", which comprises canes in active testing which have reached the 10x15, or later, stages, indicate the superior ability of certain parents to produce "select" seedlings. When converted to a percentage figure based upon the number of seedlings of the various parentages grown, this advantage is often nullified. But granting that some parents are superior to others, a very large number of seedlings must be grown in order to provide a reliable evaluation of the superiority or inferiority of a particular combination.

During the period 1928–1944, when bi-parental crossing was employed almost exclusively, some 22 varieties can be said to have reached commercial status in Hawaii. In this calculation, a cane was considered as achieving commercial status if it occupied more than 1000 acres at the time of the annual census of cane varieties. Based on an estimate of the number of original seedlings grown to maturity (3,000,000) in this period, the average frequency of ultimate commercial varieties is one in about 136,000. This is a somewhat lower proportion of commercial varieties than has been realized in some other areas where sugar cane breeding is actively carried on. While they are difficult to assess, the reasons may be related to the conditions that are being bred for and to the high level of the standards which must be exceeded. In many other countries, easily recognizable major diseases are limiting factors in sugar production, so that the primary effort is in the direction of finding varieties resistant to these diseases. Once found, these new varieties often succumb to a new biotype of the same disease or to some other disease which, though present, was at a low incidence until a susceptible host was provided. Hawaii is fortunate in that the recognized sugar cane diseases are not an important problem. This makes the job of the sugar cane breeder more difficult because he must work more directly with complexes of genes leading to indistinguishable physiological characters, resistance to unidentified negative factors, and eventually to yield. At the same time, he is faced with the necessity of changing sugar cane from a plant with inherent annual tendencies with respect to growth rates, flowering, etc., into a non-flowering perennial which maintians growth during the winter months.

To attempt to classify parents on their ability to produce commercial canes would be a long and expensive procedure. Following the "trial marriages", prohibitively large populations would have to be grown to determine with statistical significance whether one population is superior to another in terms of their abilities to yield commercial varieties[5]. Such a procedure would so limit the number of different crosses that could be tried as to be impractical. It can easily be seen that it would be useless to try to evaluate parentages on the basis of the number of elites in populations of only a thousand seedlings each if the frequency of elites is in the order of 1/136,000. The elite individual is not merely a product of the crossing of two parents, but, more specifically, it is the result of the union of a particular gamete from one parent with a particular gamete from the other. An

[5] Statisticians have determined that populations of 100,000 individuals would have to be grown in order to differentiate between a population with an elite frequency of 1/10,000 and one with 1/100,000, with the probability of .88 that the numbers of elites found will be such that the difference will be statistically significant at the .05 level.

outstanding gamete from one parent, mated with a gamete with which it fails to "nick", will produce a mediocre or inferior individual.

The belief that parents could be evaluated on the basis of average progeny performance is valid only in the absence of differences among progenies in their genetic variance. Assuming a constant level of genetic variance among progenies, the population having the highest mean would likewise have the greatest frequency of desirable extremes. However, there appears to be no basis for assuming that all progenies will manifest the same degree of genetic variance. In asexually propagated crops, any outstanding individual may be perpetuated whether it originates as an extreme plant in a population with a low flat distribution curve and perhaps a low mean, or as an extreme plant from a population with a peaked curve and a higher mean. In sugar cane breeding, widely variable genotypic distributions have definite advantages, since the extreme variants can be perpetuated without difficulty by asexual propagation.

Perhaps the most practical method of evaluating parents is that of determining the frequency with which their progeny reach the select list as related to the number of original seedlings grown to maturity. Such a method provides an approximate evaluation of the extent to which canes have been used as parents in relation to the frequency of desirable offspring. While studies of this nature are time-consuming, the results should contribute to a more intelligent utilization of the available breeding material.

BREEDING BEHAVIOR OF PARENT CANES

Whenever a parent cane is found to be homozygous for genes that possess a high degree of dominance, it is possible to predict with considerable certainty that these genes will manifest themselves in all of its offspring. Some of the wild breeding canes, for example, are homozygous for highly dominant genes for slenderness. As a result all of their offspring are slender, regardless of the stalk size of the parent with which they are crossed.

In sugar cane breeding, such a situation is the exception rather than the rule except in crosses with "wild" material. The bulk of the breeding material is highly heterozygous, and many of the genes that determine important agronomic traits show little or no dominance. The characteristics of a particular seedling are determined, not by the characteristics of its two parents, but by the genes contained in the particular egg cell and in the particular pollen grain which happened to unite to produce this seedling. Thus, a generalization as to the breeding behavior of a heterozygous parent is likely to be of little help, if not actually misleading.

If, for example, we should undertake to characterize the breeding behavior of Co. 213, our statement might read somewhat as follows: Co. 213 tends to produce slender trashy seedlings, generally deficient in growing power. To this, we should have to add: However, an exceptional Co. 213 egg cell, fertilized by an exceptional POJ 2878 pollen grain, produced 32–8560 which attained a larger acreage in Hawaii than any other variety in the history of the industry and which has proved to be an outstanding parent in breeding.

Appraisals of the breeding behavior of heterozygous parent canes are likely to be wide of the mark if they are based upon inadequate populations of offspring. On the other hand, a study of large populations of offspring will usually bring to light exceptional individuals which depart from the general rule and which thus

impose obstacles to easy generalization. These difficulties are apparent in the following observations on the breeding behavior of several parent canes.

S. spontaneum (Coimbatore) transmits slenderness, heavy tasseling and hardiness at high elevation and under poor soil conditions. In general, *spontaneum* blood must be diluted to 25 per cent or less before commercial candidates can be expected. However, Co. 205, formerly an important variety in India, is reputed to be a *spontaneum* hybrid.

S. robustum (Port Moresby) transmits high fiber, good vigor, heavy tasseling, resistance to eye spot disease, susceptibility to mosaic, and slenderness. Hybrids of good diameter are, however, occasionally found—one such exception is 32–6774, a grandparent of 37–1933.

Chunnee hybrids are in general too slender to qualify as commercial varieties in Hawaii. POJ 36 was an exception—it attained an area of 25,000 acres during the 1930's. Chunnee quarter-breeds and eighth-breeds have become important commercial varieties in many countries. 32–8560 is a Chunnee eighth-breed.

Hawaiian Uba transmits slenderness, heavy tasseling, and ability to grow under poor soil conditions. UD 50, a seedling of Uba x D 1135 is an exception in one respect—it has good stalk diameter. 32–1063 is a Uba quarter-breed. In general, Uba blood has proved useful only after dilution to 25 per cent or less. An exception is 28–4291, a Uba hybrid which attained an area of some 2700 acres in the upper lands of the Hamakua and Kohala districts.

Badila produces seedlings of good diameter and better than average sucrose content. However, when crossed with Uba the resulting seedlings are too slender to qualify as commercial varieties.

32–1063 is disappointing as a parent. Its seedlings tend to be trashy and to tassel excessively. We find among them, however, 45–1361 which rarely tassels, and 38–4744 and 39–4150 which are light tasselers.

32–6705 as a parent tends to transmit tolerance toward poor soils and high elevations. Most of its seedlings tend to tassel excessively, but 39–4753 and 42–591 are exceptions. Most of its seedlings also tend to be slender. 41–3340, however, is an exception in this respect.

32–8560, used widely as a parent, is difficult to characterize in respect to its prepotencies because its seedlings exhibit great diversity. For example, 38–4443 has remarkable tolerance for the poorest lands at the highest elevations, while 37–1933 thrives only on the better irrigated lands at lower elevations. The majority of 32–8560 seedlings tend to be heavy tasselers, as do those of most other parents. However, 39–7028, 42–591, 45–314 and 46–611, all seedlings of 32–8560, are remarkably light tasselers. As to juice quality, 32–8560 seedlings run the gamut from extremely low to remarkably high sucrose content. Similar diversity among 32–8560 seedlings can be found in respect to almost all agronomic traits. 32–8560 is evidently heterozygous for contrasting alleles at many loci.

37–1933 is better than average as a parent. Its seedlings tend to resemble it in lightness of top, in easy stripping, in a lack of tolerance for poor soils, and in tasseling heavily. 46–2010 is an exception—it has good tolerance for poor windward soils, and it rarely tassels.

The above examples will serve to illustrate the nature of the difficulties encountered in attempting to describe, in generalized terms, the breeding behavior of heterozygous parents.

CROSSING TECHNIQUE

A major advance in sugar cane breeding technique was the development in Hawaii of the use of the sulphurous acid-phosphoric acid solution for keeping tassels alive during crossing and ripening of seed. This development allowed a many-fold increase in the number of crosses that could be set up and serviced per man-day. Given unlimited resources, cane breeders would logically confine themselves to the so-called bi-parental crosses. In this type of cross, the chosen parents are paired off in isolated crossing racks with the object of producing seedlings whose male and female parents can be recorded. If the chosen female also sheds pollen and is self-fertile, there remains, of course, the possibility that some of the seed set will be the result of selfiing. However, in the selection process it is likely that the selfs with their inherent low vigor would not be selected. This is especially true under the intense competition of the bunch planting procedure.

In spite of the economies afforded by the solution method of making crosses, the bi-parental crosses are costly as compared with some of the other techniques described below. For this reason, and in spite of the advantage of knowing both parents, only about half of our man-power resources during the crossing season are devoted to bi-parental crosses. Bi-parental crossing is restricted largely to crosses between proven parents, crosses for the development of breeding canes. and crosses which cannot be made in the more efficient "area" cross method,

BREEDING PROCEDURES

The extreme rarity of elite genotypes in seedling populations is the crux of the problem of breeding better canes. As suggested above, this is largely due to the genetic complexity of the characters leading to yield. In a diploid, such as corn, calculations may be made to determine the number of progeny plants that must be grown to provide a given chance of incorporating a desired combination of homozygous gene pairs in a single individual by selfiing when the parent is heterozygous. Assuming ten heterozygous pairs of genes in the parent, the average frequency of a particular combination of homozygous alleles is $\frac{1}{4}^{n}$, or $\frac{1}{4}^{10}$ = 1/1,048,576 in this case. To cite an example more closely approximating the situation in sugar cane, assume two allo-octoploids, which behave genetically like the noble canes, with only 20 loci influencing yield in each. Assume further that variety A has the first ten of these loci in the heterozygous condition and the second ten homozygous recessive; Variety B has the second ten in the heterozygous condition and is recessive for the first ten. With free recombination, to recover all 20 dominant genes in one progeny plant ($P = 0.95$) would require a population of 3,141,534 individuals. These examples are, of course, oversimplified but they serve to illustrate the nature of the problem.

Genetic linkage of desirable with undesirable genes located on the same chromosome is an important consideration in that it reduces the chances of achieving desirable gene combinations. Genes so located tend to be inherited together rather than to be assorted independently in the formation of pollen grains and egg cells. "Crossing-over" allows some recombination of such genes but at a reduced frequency, depending primarily on how close together the genes are situated. Thus considerably larger numbers of individuals would have to be grown to extract a desirable gene from between two undesirable ones close together on the same chromosome, than would be necessary if the genes were assorted independently.

In dealing with polygenically controlled quantitative characters, as we are, it is probable that the desirable genes are widely scattered among the chromosomes and that many of them are closely linked with undesirable genes.

There are, of course, several ways in which to meet this difficulty of rarity of elites. One obvious approach occurring to laymen and plant breeders alike is an attempt to increase the frequency of elites in the population. For example, devoting a portion of the program to selfiing and selecting among the selfs on a progeny basis is genetically sound, but from a practical standpoint the usefulness of this procedure in sugar cane breeding needs further evaluation and study.

SELFING

Selfing is employed in the breeding of corn and other seed propagated crops with the prime object of isolating and perpetuating a given genotype, so that this genotype may be used repeatedly in breeding to produce uniform single crosses. Selfing may have some application to sugar cane breeding, but not as a means of perpetuating a particular genotype, since any genotype in sugar cane may be perpetuated asexually. In our philosophy, "repeatability" of crosses does not appear to be important because it appears to be more profitable to use the new selected elite clons in further breeding than to repeat the crosses which produced them. As in other crops, selection among selfs may be of advantage for those qualitative characters which are not influenced by the normal reduction in vigor which accompanies selfing. Thus selfing could be a useful procedure in concentrating genes for disease resistance, etc.; but as in corn, selection among selfs for yield and other genetically complex characters would almost certainly prove to be inefficient. Selection among selfs on the basis of their progeny's performance is genetically sound. However, while the over-all goodness of the progenies may be improved at the expense of years of effort, the frequency of elites may not be increased. Progenies of selfs naturally have less genetic variability, and genetic variability is of the highest importance in the production and selection of extreme individuals. Another disadvantage of the selfing approach to improve the quality of seedling populations lies in the time and effort involved in the process as related to the fluidity of the selection standards needed to meet the changing demands of the industry. Inbred parents may not meet the requirements of a breeding cane by the time they have been selected and tested.

Aside from the delay inherent in the selfing approach due to the time required to grow the selfs and to evaluate them, there is another important disadvantage which may be peculiar to Hawaii. Under two-year cropping, tasseling is one of the most serious limiting factors in sugar production. It seems logical to assume that, because of their reduced vigor, only those selfs which are genetically heavy tasselers would produce sufficient tassels to be useful in the breeding program. This would naturally lead to a greater preponderance of heavy tasselers among the progeny of such selfs. When rare tassels of light tasseling varieties are available, it seems doubtful that to use them in producing selfs represents the most efficient and profitable use to which they may be put. In addition, approximately one-half of the breeding canes in which we have the greatest interest could not be selfed due to male- or self-sterility.

In the case of asexually propagated crops, it appears to be more practical to evaluate the heterozygous clons for breeding behavior through progeny study of

selection rates or other means. In this case, genetic variability among the progeny is not narrowly restricted as it is in progenies of selfs, and thereby chances of producing elite individuals of commercial promise are better at every stage of the program. Except in certain cases of polysomic inheritance, a self from a given variety can produce no gametes which are not also produced by the parent variety, although the gametes may be in different proportions. In fact, the gametes produced by an individual self will have a greatly reduced range of variability as compared with the gametes of the parent.

Twenty-five years ago, when interest in selfing as a breeding technique was strong, Uba was an important parent in the breeding program. Consequently, efforts were directed toward obtaining selfs of Uba in the hope that one or more such selfs might prove of greater value as a parent than Uba itself. Uba produces no pollen during the normal tasseling season, but it was discovered that some pollen was being shed by off-season summer tassels found at Honokaa. By collecting such summer tassels in quantity, a few Uba selfs were obtained. Some of these were eventually used in crosses. But while Uba itself produced such canes as 28–4291 and 28–4399 (the parent of 32–1063), no useful progeny were obtained from the Uba selfs, in spite of the disproportionate amount of effort expended in this direction.

Similarly, POJ 2878 was selfed as soon as tassels became available for breeding. But while POJ 2878 itself produced a number of commercial varieties when used in crosses, including 31–2806, 32–1063, 32–8560 and 38–2915, the selfs obtained from POJ 2878 produced no canes of importance.

Attempts to utilize selfing as a means of accelerating progress in breeding encounter the following difficulties:

1. Because of pollen sterility or self-sterility, it is impossible to obtain selfs of many of the parents from which selfs may be desired.

2. The selfs obtained are almost without exception weaker and less fertile than the varieties from which they were derived, a fact which results in higher per seedling costs.

3. As a result of the weakening effect of intense inbreeding, many of the selfs fail to tassel. Since only the heavier tasselers in the population produce tassels, selfing aggravates the difficulty of breeding toward freedom from tasseling.

4. Selfing increases greatly the length of time required to bring together in a single individual the desired traits of a number of ancestors. If instead of using Co. 213 and POJ 2878 "as is" in crosses, a policy of selfing before crossing had been rigorously followed, the obtaining of the Co. 213—POJ 2878 combination to produce the equivalent of 32–8560 would have been long delayed. Similarly, if selfing prior to the combining of the 32–8560 and 34–1874 blood lines had been insisted upon, we might still be without the equivalent of 37–1933.

Under the long cropping practices of this industry, even a sketchy evaluation of a new cane requires at least six years of testing. Thus the interval between generations in the step-by-step combining of the better representatives of diverse bloodlines is at best a long one, even without the interposing of selfed generations between each step in the synthesis. Assuming that a particular combination of genes essential to success under a given set of conditions can be had only by concentrating the desirable genes originally dispersed among eight different ancestors, the bringing together of the required gene combination would entail a

minimum of three generations of crossing even though the heterozygous parents are used "as is" in further crossing. Allowing a suitable interval between generations for evaluating the progeny, such a three-generation project would require fifteen to twenty years. The interposing of only one generation of selfing between each generation of crossing would double the number of years required for bringing together in a single individual the desired genes originally dispersed among its eight great-grandparents. Since commercial ventures, including investments in research, are of necessity working against time if only for the reason that interest charges are a function of time, selfing as a breeding technique would have to offer very great advantages in order to compensate for the extra time required.

Whether selfing can or cannot be expected to offer sufficient advantage to warrant its utilization in any particular breeding program depends largely upon the answer to a single question—how important is it that the results achieved be sexually reproducible? The answer to this question depends in turn upon whether the commercial crop must be grown from true seed or whether it can be propagated asexually, by cuttings, tubers, budding or grafting.

Among crops which cannot be propagated asexually and which must therefore be propagated by means of true seed, sexual reproducibility is of crucial importance. A single outstanding individual is of little consequence unless some way can be devised to reproduce it in large numbers. To this end, selfing is an indispensable tool.

Among the asexually propagated crops, on the other hand, the single outstanding individual is of transcendent importance, while the sexual reproducibility of such an individual in large numbers is of little consequence. Since 37–1933, for example, can be reproduced at will by cuttings, no advantage would accrue from being able to grow from true seed a population all members of which are identical with 37–1933. In sugar cane, as in other asexually propagated crops, once an outstanding individual has been realized, asexual propagation provides the required reproducibility.

In crops such as corn which cannot be propagated asexually, sexual reproducibility must somehow be achieved if the superior genotype is to be utilized on a field scale. As already indicated, selfing provides a powerful tool in the attainment of sexual reproducibility in crops that must be grown from true seed. The outstanding results obtained by the employment of selfing in the breeding of seed-propagated crops has fully justified the time and effort entailed by the selfing procedure. In the breeding of crops that are asexually reproducible, selfing as a breeding tool offers no corresponding advantage to compensate for its very considerable cost in time and money.

Selfing as a technique is of definite importance to sugar cane breeders in two ways. Information as to the degree of self-fertility is an aid to the breeder both in choosing parents for crossing and in making selections in progenies of canes which are self-fertile. Selfing may also be helpful in providing segregants which, for one reason or another, may be more useful in breeding than the parent from which they were derived. For example, among selfs of a variety which tassels too early to be used may be found a late-tasseling segregant. Among the rare selfs of a highly pollen-sterile variety may be found a good pollen producer. It must, of course, be recognized that the value of such a self is limited by the fact that

it represents only a small sample of the germ plasm of the heterozygous parent from which it was derived.

A considerable amount of selfing has been done at this Station during the past twenty-five years for the purpose of evaluating the degree of self-fertility of the parent canes and of developing breeding canes. Many thousands of selfs have been grown. Some 2435 have been selected and assigned permanent numbers in the Master File, representing the selfing of about 250 different varieties. Still others have been selfed without success due to self-sterility.

Many of these selfs have been used in further breeding and a few have been selfed a second time. During the past twelve years over 26,000 seedlings have been grown from crosses involving a self as one parent. Since 1931, 288 seedlings having a self as one parent have survived initial selection and have been assigned a permanent number. None of these has proved outstanding enough to warrant enthusiasm over the use of selfs as parents. However, selfing will undoubtedly be continued on a limited scale for further exploration of its usefulness as a breeding procedure, as well as for the two purposes outlined above: first, evaluation of self-fertility and second, development of segregants which may be more useful in the breeding program.

Alfalfa breeders, who were at one time imbued with a belief in the necessity for selfing as a means of preserving their parental material for use in single and double crosses, have now generally given up this approach in favor of more efficient procedures. Following the development of practical methods for asexual propagation of breeding clons, outstanding plants (equivalent to single crosses) were selected for their general combining abilitv by means of a polycross test. Crosses of these selected clons were then made and the yield of the various progenies (equivalent to double crosses) were compared. Seed of the better hybrids could then be produced on a commercial basis through asexual propagation of the heterozygous parent clons in the crossing blocks.

Inbreeding (mating of close relatives) as a breeding principle has been widely used in our breeding program and has probably been of considerable importance in increasing the gene frequency for characters indispensable to success under the environmental conditions and agronomic practices of our plantations. Canes with POJ 2878 or 32–8560 blood, for example, are numerous in our breeding collection and many of the crosses made, both bi-parental and melting pot, bring in a high proportion of these blood lines from both sides.

The basic procedures employed by this Station are: the rough evaluation of a large number of heterozygous parents each year, one of the purposes of the melting pot which is equivalent to a polycross; the practice of making trial marriages; and the exploitation of what appear to be the better parents so revealed. No sugar cane breeder, in fact no plant breeder, can predict with accuracy the particular cross from which the next leading variety will come. Certainly some crosses are to be favored over others, but the fact remains that many of our outstanding seedlings come from parents not on the list of preferred parents. The inability of the breeder to predict the cross that will provide the next super-cane led to the desire for a practical means of increasing the diversity of combinations.

MELTING POT CROSSING

The melting pot procedure was first explored with the object of evaluating the breeding behavior of a large number of canes at minimum expense. The melting pot is essentially an adaptation of the polycross technique widely used in the breeding of certain other crop plants. A diverse but nevertheless highly selected group of "female", or pollen-sterile, varieties is admitted into the melting pot. The number of tassels of any particular female variety utilized in the melting pot depends upon its interest to the breeder. The male-fertile tassels also comprise a number of varieties, but they are limited for the most part to the best canes and to proven parents. Male-fertile varieties likewise are included in proportion to their breeding interest. Seed is harvested from both the pollen producing and non-pollen producing tassels. Only the female parent of the resulting progeny can be known with certainty.

After several years of experience, it became apparent that the melting pot was producing a large number of seedlings at a low cost, and that the populations from the melting pot contained practically as high a proportion of selectable material as did the progenies from the better bi-parental crosses and trial marriages. During World War II, labor shortages restricted the breeding program almost entirely to melting pot crossing. Now, even with increased facilities for bi-parental crossing, it is felt that the melting pot procedure has a definite place in the breeding program—that it can stand on its own merits.

A recent study of the 49- and 50-seedlings which have achieved select list status in 1952 shows that 1/3235 of the seedlings from bi-parental crosses reached the select list while the ratio for the melting pot was 1/3681. This slight advantage in favor of the bi-parental crosses is more than offset by the fact that this type of cross, accounting for more than half of the crossing effort, realized only 13.5 per cent of the seedlings on the select list. The other 86.5 per cent of the select list canes came from the remaining portion of the crossing effort allotted to melting pot crossing. Of the 679 canes of the 49– and 50-series on the 1952 select list, 587 came from melting pot crosses and only 92 from the bi-parentals. This situation reflects the advantages of melting pot crossing in affording a large number of combinations at low cost. It also suggests that the small proportion of the total number of all possible combinations that the breeder is able to achieve by means of bi-parental crossing is hardly likely to include all of the superior combinations, nor will it necessarily include the best of all such possible combinations.

It should be emphasized that a lack of knowledge of the paternity of seedlings from the melting pot in no way precludes their use in the breeding program. Some of our most promising parents have come from the melting pot, as, for example: 39–723, 39–3633, 39–5747, 39–7028, 40–1179, 40–1184, 41–1181, 43–1616, 44–1117, 44–2818, 44–3098 and 45–2120.

Some of the factors which led to the development and use of the melting pot technique in Hawaii were:

(1) the effective crossing season lasts only six weeks,

(2) the skilled personnel available to carry out the crossing work is limited,

(3) the number of bi-parental crosses that can be made by the limited staff during the short crossing season

amounts to less than one per cent of the number of bi-parental combinations that might be advantageously explored,

(4) the prediction with satisfactory precision of the degree of superiority or inferiority of each of the many thousands of possible combinations of parents available to the breeder is impossible, and finally

(5) the restricting of the breeding campaign to bi-parental crossing, and thus limiting the number of combinations to less than one per cent of the total number of promising matings, makes it likely that the best combinations would be missed.

In the melting pot, every effort is made to achieve random pollination. The following factors contribute to the diversity of the combinations realized from the melting pot:

(1) the blooming period of the individual flowers of a tassel extends over a period of five to ten days,

(2) the positions of the tassels in the melting pot are rearranged periodically,

(3) a given variety is represented in the melting pot by two or more tassels each placed at random,

(4) tassels of a given variety may be introduced into the melting pot over a period of several weeks, and

(5) shifting winds cause corresponding shifts in the direction of pollen drift.

Given 200 selected parents, for example, the plant breeder could make 19,900 combinations, excluding selfs and reciprocals. In view of the inability of the plant breeder to effectively predict which cross will yield the next commercial variety, there would be few of these 19,900 combinations in which he would have no interest. To make all of the possible crosses in separate bi-parental combinations would be economically prohibitive. Placing a number of tassels of each of these 200 canes together in a melting pot will not achieve all of the 19,900 possible combinations, but it will be more effective than bi-parental crossing in approaching this objective.

In recent years, melting pots (polycross areas) have been set up for specific purposes, e.g., breeding for mauka (high elevation) conditions, intercrossing of only the most elite breeding canes (the "super" melting pot), further sampling of wild material, etc. Future years are likely to see further expansion in the number of specialized melting pots. Melting pots are planned for increasing the diversity of combinations among (1) canes adapted to the best leeward conditions, (2) for sibbing among 37–1933 hybrids, and (3) for sibbing among 39–7028 hybrids.

Misgivings as to the soundness of the melting pot procedure have apparently resulted from a lack of appreciation of the fact that the pollen-producing canes admitted to the melting pot constitute a highly selected group, each member of which has been chosen for superiority in one respect or another from among thousands of candidates. It has been recognized from the first that the quality of the parent material introduced into the melting pot determines the quality of the resulting combinations.

The fact that greater returns per dollar expended are being realized from the melting pots than from bi-parental crossing is interpreted as reflecting the advantage inherent in the wide diversity of combinations provided by the melting pots over the small number of combinations attainable through bi-parental crossing. Other things being equal, the greater the diversity among the seedling populations, the greater the likelihood of discovering an extreme "plus" variant. Greater diversity also provides greater mobility in meeting changing objectives and in dealing with whatever new negative factors may be encountered.

BI-PARENTAL CROSSING

As compared with the melting pot technique, the making of bi-parental crosses is expensive and time-consuming. However, bi-parental crossing remains the major part of the sugar cane breeding program of this Station. Its primary use lies in the exploitation of the most desirable parents in combinations considered to have the highest likelihood of producing new commercial varieties. Bi-parental crossing is necessary whenever it becomes desirable to know both parents of the progeny. Since it is essential that the pollen population in the melting pot be maintained at a high level of genetic superiority, it becomes necessary to exclude wild or unselected male parents, or male parents lacking the complex of genes leading to the "Hawaiian type" of sugar cane. For this reason, recourse must be had to bi-parental crossing when such unadapted germ plasm is to be introduced into the breeding program.

During recent years somewhat more than 50 per cent of the total effort of the crossing program has been directed at making bi-parental crosses. This effort is at present yielding a little more than ten per cent of the canes on the "select list". This discrepancy between effort expended and returns realized stems partly from poorer germination from bi-parental crosses than from melting pot crosses, and partly from the fact that many of the bi-parental crosses are designed to develop breeding canes from introduced and wild material rather than to produce commercial canes.

Efficiency in bi-parental crossing has been improved through the "area cross" technique. In each such area, a single source of pollen (male parent) is used with a number of pollen-sterile female parents[6]. The fact that a number of bi-parental crosses involving the same male can be made in a single crossing rack makes for ease in servicing and for efficient utilization of the tassels of the male parent.

One of the serious limitations of bi-parental crossing is the inability of the breeder to "call his shots", i.e., to predict which combinations are most likely to produce new and outstanding commercial varieties. For this reason, many bi-parental crosses, called trial marriages, are made using parents which on the basis of their melting pot progeny have shown promise as breeding canes. But the superiority of the two parents provides no assurance that either the progeny as a whole, or single individuals within the progeny, will be outstanding. An outstanding variety is the result of the union of two gametes, one from the male parent and the other from the female parent, which "nick" together to ameliorate each other's deficiencies. The level of goodness of our present commercial varieties is such that a combination of gametes superior to the best of these is a rare occurrence.

[6] This is essentially what is known to corn breeders as the "top cross" technique of making crosses.

A philosophy which embraces a program limited to bi-parental crosses assumes that the small number of combinations that can be executed in this way during the relatively short crossing season will include the best possible combinations among the available parent canes. The adage among sugar cane breeders that "one never knows where the next super-cane will come from", suggests a recognition of the difficulties and uncertainties which confront the breeder in this respect. To compensate for his inability to predict the combinations of parents which will produce the best new varieties, the breeder must resort to making a wide diversity of combinations among what he believes to be the most promising parent canes at his disposal. And the more such combinations he can achieve, within his budget, the better are his chances for success. At this Station, bi-parental crossing is considered indispensable in achieving combinations which are believed to have exceptional promise, while the melting pots are relied upon for economical production of a wide diversity of combinations which otherwise could not be made.

PROPAGATION AND TESTING

The making of a large number of crosses cannot, of itself, guarantee rapid progress in sugar cane breeding; nor is the mere production of hundreds of thousands of seedlings per year indicative of a good breeding program. Outstanding seedlings will be recognized as such only if selection is effective. At this Station the techniques of germination, transplanting into field nurseries, and selection at various levels, have been developed with the dual aims of increasing efficiency in handling large numbers and of making selection more effective.

The "bunch" method of transplanting seedlings from the original flat into the field is peculiar to Hawaii. In other countries, space planting of individual seedlings is the rule.

The bunch method involves the planting of seedlings in bunches of 5 to 15 seedlings each, the bunches being spaced from 12 to 24 inches in the row. The object of this procedure is to reduce transplanting costs and to accommodate more seedlings per acre. Bunch planting results in a five- to ten-fold increase over space planting in the number of first-year seedlings that can be grown on an acre of land.

The bunch planting method is not without its disadvantages. Since tillering is restricted by competition, selection at one year of age must be on a single-stalk basis. Therefore, selection in bunch planting can hardly be as effective as in space planting where a whole stool of each seedling may be evaluated. Selection in bunch planting is based upon vigor and over-all well-being, freedom from tasseling and diseases, satisfactory stalk size, fiber, juiciness, and freedom from obvious defects. It is estimated that under the present program approximately a million seedlings each year survive until selection at twelve months of age. Some thirty to fifty thousand seedlings per year are selected from the original bunch seedling nurseries for further trial.

The manner of planting employed in the nursery may affect selection in several ways. As indicated above, bunch planting precludes an evaluation of stooling ability. It has been suggested that the bunch planting procedure would favor the vigorous, fast growing seedlings which may also tend to be deficient in stooling ability and in juice quality. But the fact remains that practically all of our newer

varieties, including canes with heavy stooling and good juice, have been selected from bunch plantings.

Under the space planting procedure with today's highly heterozygous parents, a considerable proportion of the nursery area would be occupied by weaklings and runts. The competition that prevails in the bunch nursery tends to eliminate these weaklings in the early stages of growth. Thus it is felt that the bunch planting technique dovetails rather nicely with the melting pot system of crossing. The melting pots provide a large number of seedlings from a wide diversity of combinations at a low cost, while the bunch planting procedure provides the means whereby large numbers can be accommodated economically in the field.

In keeping with the aim of finding better varieties for each of the various conditions under which sugar cane is grown in Hawaii, bunch plantings are made in a number of different environments each year. While most of the new seedlings are planted at regional variety stations under the jurisdiction of the Experiment Station, a limited number of flats of bunch seedlings are supplied to plantations having unique conditions for which new varieties are needed.

Parentage is the major consideration in choosing the location to which the seedlings are sent. Certain of the areas committed to bunch planting are operated on an annual basis, being planted each year with a new lot of seedlings, selected at 11 to 12 months of age, the unselected residue being harvested immediately and the field then prepared to receive the next lot of seedlings. This is a further effort in the direction of efficient utilization of facilities in order to accommodate a maximum number of new seedlings each year.

Because selection in bunch planting is based upon individual stalks, the selected seedlings can be planted only at a single location. The selections from the bunch nursery at a particular station are usually planted in 5 x 3 tests at the same station. If because of space limitations the selected seedlings must be planted at a different location, parentage serves as a guide in determining the regional station to which a newly selected seedling will be sent.

A basic feature of the preliminary testing program of this Station is the early distribution of each selected seedling to a number of different environments. This is first done when the seedlings are selected from the 5 x 3 plantings. At this stage they are sent to at least two, preferably three, and, in many cases, four or more, different variety stations for 5 x 6 planting. It is at this stage that each seedling is given its permanent number and place in the Master File. Selection from 5 x 6 may result in still further distribution, in repeating in 5 x 6, or in advancement to the 10 x 15 stage. In arriving at a decision as to appropriate action, the selector is guided not only by the appearance of the cane before him, but also by the Master File record of its performance at other stations and in other plantings at the same station.

The principle of early decentralization as exemplified by the utilization of a network of regional stations in the preliminary testing of new seedlings is not universally followed elsewhere. In some countries, the populations of new seedlings are reduced to a small number through successive stages of selection at one station prior to distribution and testing in other locations.

The network of eleven variety stations in locations representative of the major ecological conditions under which sugar cane is grown in Hawaii, provides the opportunity to gauge the over-all performance and the specific adaptation of a

seedling at a relatively early stage. Some of these stations start with bunch planting, all of them have 5 x 3, 5 x 6, 10 x 15 and 30 x 30 plantings each year. In addition, each plantation receives some fifty or more seedlings per year for 10 x 15 testing under each of its own particular conditions. These are seedlings that have shown promise at the regional stations or on other plantations. These 10 x 15 plantings are selected and advanced to plantation 30 x 30's with the aid of the Master File information in the same manner practiced at the regional stations.

The sites for the variety stations, which form the foundation of the preliminary testing program, have been chosen with a view to providing a wide range of conditions representative of the major ecological zones under which sugar cane is grown in Hawaii. Some of these stations represent poorer than average conditions. For example, the Kauai Variety Station is in a poor growth, heavy tasseling area; the Ewa Variety Station receives saline irrigation water; the irrigated Maui Variety Station has characteristically tight soils in a windswept area; the Kohala station is typical of the more severe conditions of that area. The variety stations represent a wide range of conditions. There are irrigated, semi-irrigated and unirrigated stations; stations where tasseling is heavy, medium, light, and nil; stations on residual and on alluvial soils; stations in heavy tonnage and in light tonnage situations; stations where certain diseases are, or were, important; and stations free of recognized diseases. It has been felt that through testing of new seedlings under representative conditions, greatest over-all efficiency can be realized in the selection process.

In former years, considerable emphasis was placed on ratoon selection. Experience showed that as genes for the Hawaiian type accumulated in the seedling populations, very few seedlings were selected in the ratoons which had not already been selected in the plant crop. What is more, only a small number of seedlings selected in the plant crop were later disqualified solely because of poor ratooning ability. After consideration of the advantages and disadvantages of ratoon selection, it was deemed more efficient to select only in the plant crop. This change had the effect of greatly increasing the area available for early testing —almost twice as many seedlings could be processed per unit area as under the former procedure.

Under present practices, most of the field nurseries are harvested and plowed every year immediately after selection, and are thus used for a new field nursery every year. Fields in 5x3, 5x6 and 10x15 plantings are selected at 12 months and harvested and plowed on a two-year cycle, there being no ratooning. Of course, the 30x30 preliminary yield trials are ratooned and so fall into a four-year cycle.

CONCLUSION

Implicit in a philosophy that stresses the advantage of large seedling populations and diversity of parental combinations, is the assumption that when an outstanding genotype is present in a population, it will be recognized as such. Smaller numbers should permit a more intensive examination of each seedling to make sure that an outstanding individual will not escape detection. Large populations can be dealt with effectively only by prompt and rigorous discarding of the mediocre material which constitutes the bulk of even the best populations. Such prompt and rigorous selection is required in order to permit the necessary

concentration upon the small remaining fraction of elite seedlings, but it must inevitably entail the risk of discarding an occasional superior individual.

This risk has been recognized as inherent in the extensive approach. However, it is regarded as less to be feared than the risk entailed by the intensive approach, which by devoting a larger amount of space and effort to each of a smaller number of seedlings, would automatically preclude the exploration of a considerable proportion of the combinations now being examined under the more extensive approach.

In considering the relative merits of the extensive versus the intensive approach, cognizance must be taken of the fact that the greater the superiority of a particular new seedling, the less likely it is to escape the selector, a circumstance which provides the extensive approach with an inherent safeguard. The intensive approach would possess a corresponding safeguard if it could be shown that, as the number of seedlings grown is reduced either by a more exacting choice of combinations or by a reduction in the number of seedlings per combination, the likelihood that an outstanding seedling will be included in the reduced population is correspondingly increased. We have no reason to believe that such would be the case.

The course now being followed by this Station is based upon thorough consideration of the advantages and shortcomings of the extensive versus the intensive approach. It is felt that a still further revision of our procedures in the direction of a more extensive approach may yield even greater returns per dollar invested in sugar cane breeding in Hawaii.

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